Demonstration of subaqueous disposal of mill wastes, Jasper County, MO

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ABSTRACT: The Jasper County Superfund Site in Jasper County, Missouri contains more than 5,000,000 cubic yards of mill waste from the historic lead and zinc mines of the Tri-State Mining District. Remediation alternatives evaluated in a Feasibility Study (NewFields 2003) include conventional soil caps, engineered repositories, and in-place revegetation with topsoil and municipal biosolids. One alternative is to use the mill wastes as fill in mine subsidence pits, the surface depressions resulting from collapse of underground mine workings. Regulatory concerns that subaqueous disposal would negatively impact water quality in the shallow aquifer led to placement of 58,000 cubic yards of zinc mill tailings as unsegregated fill in a flooded one-acre subsidence pit. The tailings contain about 2 percent zinc and lesser amounts of lead, cadmium, and iron. Monitoring in nearby wells and ponds did not detect any significant changes in water chemistry. Permeability and gradient information from the field test was used to calculate zinc loading to the shallow aquifer.

1 BACKGROUND

The Feasibility Study (FS) for the Mine and Mill Waste Operable Unit, OU-1, Jasper County Site was prepared by the Jasper County Respondents for the U.S. Environmental Protection Agency, Region VII (EPA), with assistance from the Missouri Department of Natural Resources (MDNR), the U.S. Fish and Wildlife Services (USFWS), and the Missouri Department of Conservation. The FS evaluates remedial alternatives that would improve water quality in streams and reduce ecological risks through the remediation of surficial mill wastes and affected soils in the Missouri portion of the Tri-State Mining District, one of the largest lead-zinc districts in the world. One of the alternatives evaluated in the FS is subaqueous disposal of mill wastes in mine subsidence pits, the surface depressions formed as a result of the collapse of numerous underground lead-zinc mines. Under this alternative, 3.8 million cubic yards (cy) of surface mill wastes would be placed in the subsidence pits, then capped and vegetated to isolate the material from erosion and rainwater leaching, thus positively affecting surface water quality and sediment metal concentrations. The caps would limit infiltration and establish reducing conditions. In contrast to the existing aerobic environment, subaqueous disposal is designed to establish a stable environment for sulfides due to the elimination of oxygen. The maximum concentration of dissolved oxygen found in surface water is about 25,000 times lower than that found in the atmosphere. As the rate of sulfide oxidation is partly dependent on the concentration of oxygen, it follows that reduced rates of acid generation and metals release will occur in a subaqueous setting relative to an exposed surface setting (Robertson *et al.*, 1997). In addition, the rate of oxygen transfer through water is nearly 10,000 times slower than in air, so that the reduced oxygen supply underwater may eventually result in anoxic conditions where sulfide minerals are stable. When anoxic conditions are achieved, metals release from sulfide minerals will be controlled entirely by their very low solubility in water.

Given the reduced oxygen supply, the geochemical changes that are expected upon disposal of oxidized mill waste into a subaqueous environment are:

- A shift over time from strongly oxidizing to reducing conditions (drop in Eh)
- Slight increase in pH to mildly alkaline (pH = 7.5 to 8.5) conditions
- Reduced rate of sulfide oxidation and ARD generation.

There was regulatory concern that subaqueous disposal of mill wastes in subsidence pits could impact groundwater quality due to metals leaching from the backfilled wastes, and could negatively impact surface water quality if there was a hydraulic connection between groundwater and surface water. A demonstration of subaqueous mill waste disposal was conducted in the Waco subdistrict of the Tri-State Mining District.

The Waco subdistrict is located about 13 miles northwest of Joplin, between the towns of Waco, Missouri and Lawton, Kansas, straddling the Kansas-Missouri border. The district was first opened in 1917 and produced over 300,000 tons of zinc concentrates. The surface formations are Pennsylvanian shale and Mississippian limestone. The Pennsylvanian shale has an average thickness of between 40 and 60 feet over most of the subdistrict but has eroded away in some places. The ores were mined from the Mississippian Boone limestone from various ore horizons down to 300 feet below ground surface.

Many thousands of cubic yards of chat and tailings are present at the surface that contain the sulfide minerals pyrite (FeS_2), galena (PbS), and sphalerite (ZnS), among others. Chat is composed mostly of sand to gravel-sized chert (silicified limestone) fragments from the crushing and milling of lead-zinc ore by gravity separation. Tailings are fine-grained sand and silt-sized wastes from either the gravity separation or from the froth flotation beneficiation process.

2 HYDROLOGY

The Demonstration Site lies along the Missouri-Kansas border at an elevation of approximately 890 feet mean sea level (MSL). Annual rainfall is around 40 inches and local runoff generally moves from west to east toward the Spring River, a major interstate stream located approximately one mile east of the Site. Most of the runoff at the Demonstration Site is intercepted and retained by subsidence pits that function as runoff catchment basins. Pond water levels rise and fall, sometimes dramatically, with rainfall. The demonstration was conducted during a period of drier than normal conditions and water levels in the subsidence pits dropped to below average levels. Pond water levels are 2 to 4 feet higher than water levels in the shallow aquifer indicating a downward hydraulic gradient.

The shallow aquifer is generally unconfined except where the Pennsylvanian shale is present above the limestone and the shale can act to confine the shallow aquifer. Recharge is probably slow through the massive limestone and shale but greater in naturally brecciated areas and mined areas where the permeability is higher. Recharge to the shallow aquifer may also occur through exploration drill holes, collapsed mine shafts, and subsidence pits.

The regional direction of flow in the shallow aquifer is west to northwest from Missouri into Kansas with a gradient roughly 20 feet/mile (Spruill 1987). Locally, the hydrologic divides correspond to topographic divides and the movement of groundwater is from the divides to the streams (Barks 1977). As such, the local gradient may be eastward or southeast to the Spring River. There are no domestic wells in the Waco subdistrict and water level measurements in two shallow aquifer wells drilled for the demonstration do not clearly establish a gradient. Of measurements taken between February 2002 and April 2003, five show a slight gradient from east to west, two show the reverse, and one is essentially flat.

Water in the shallow aquifer is mineralized and regularly exceeds secondary drinking water standards for iron, manganese, and sulfate. Water within the mines is poor with low pH and elevated cadmium, lead, manganese, and zinc concentrations.

3 EXCAVATION AND P4 POND BACKFILLING

The P4 Pond was backfilled with flotation tailings between March and July 2002 by A & M Engineering and Environmental Services (A & M) of Tulsa, Oklahoma. Construction supervision was provided by A & M. NewFields managed the project for Sunoco, Inc.

After constructing haul roads, staging areas, and a chat dike that prevented surface water inflow into the P4 pond, an 11-acre tailings area was cleared and grubbed. Tailings were scraped into winrows using wide-track, low-pressure dozers. Twenty cy scrapers transported the tailings 1,100 feet to a dump area where a dozer bladed the material into the pit. No compaction was performed, beyond that provided by the weight of the dozers. Pond water was periodically pumped from the pit. Settlement was anticipated and a surcharge of tailings was placed to form a gently sloping mound 3 to 4 feet above the surrounding grade. In all, an estimated 58,000 cy of tailings was placed in the pit, capped by 1.5 feet of topsoil. The remaining tailings in the excavated area were graded to provide positive drainage and each acre received a mix of 50 tons topsoil and 50 tons (dry weight) Class B municipal biosolids from the City of Fayetteville, Arkansas. Seeding is scheduled for Fall 2003.

Project costs, including site preparation, construction engineering, haul road improvements, equipment mobilization, health and safety plan, and pumping, were approximately $4.50/cy of tailings and $20,000 for the cap (not seeded). These figures do not include costs for project planning, bid preparation, landowner negotiations, site mapping, surveys, well drilling or permitting, monitoring, materials testing, reclamation of excavated areas, or project management/oversight functions provided by NewFields, EPA, MDNR, or KDHE.

4 PHYSICAL PROPERTIES OF TAILINGS

A sample of the tailings used to backfill the pit contained 18,730 mg/kg zinc, 570 mg/kg lead, and 144 mg/kg cadmium based on laboratory analysis performed October 9, 2002. This result is consistent with tests of other tailings impoundments in the Waco subdistrict. An acid-base account using method EPA-600/2-78-054 indicated that the tailings are non-acid forming, based on a pH above 4 (7.6) and excess carbonate was available to neutralize the acid generation potential (measured as total sulfur content).

In July 2002, samples of in-pit tailings were obtained using a hollow-stem auger drill rig (Mohawk Drilling, Tulsa, Oklahoma) from the approximate center of the filled pit.

Representative samples from a depth of 3.5 to 5 feet were tested at Advanced Terra Testing (ATT, Chris Wienecke, Lakewood, Colorado) for grain size, density, permeability (hydraulic conductivity), and one-dimensional consolidation.

Based upon the grain-size distribution (ASTM D 422), and assuming the Atterberg fines have a classification of CL, the sample tested has a Technical Classification (ASTM D 2487) of "CL, Lean Clay with Sand". The tailings material tested contained approximately 7 percent fine gravel, 18 percent sand-size constituents, 54 percent silt-sized material and 21 percent clay-sized material. Approximately 75 percent of the tailings passed the #200 (75-micron) sieve. Average wet density of the material collected above the water table was 128 lbs/cu.ft, with an average dry density of approximately 110 lbs/cu.ft. The sample was subjected to back-pressure, saturated hydraulic conductivity testing (ASTM D 5084), yielding an hydraulic conductivity of 2×10^{-7} cm/sec.

The consolidation test (ASTM D 4546, Method B) indicated that vertical settlements on the order of 0.03 foot/foot of tailings should be anticipated. It is important to note that the consolidation tests were performed on samples collected from above the water table; therefore, the overall consolidation of the tailings was under-predicted. The tailings exhibit a slight swelling of approximately 1 percent vertical swell under a 1-foot vertical load, the "seating load". The tendency to swell is overcome by the weight of the overlying tailings.

5 MONITORING

Baseline water chemistry was established by sampling at three neighboring ponds and two monitoring wells drilled on July 18, 2001 and February 20, 2002. To evaluate chemical changes that might occur as a result of placement of the tailings in the subsidence pit, sampling rounds were conducted on September 4, 2002, November 26, 2002, and April 14, 2003. Pond and well locations are shown on Figure 1.

Since the groundwater flow direction from the backfilled pit was unknown, survey reference markers of known elevation were established and pond and well water levels were recorded during each sampling round. Prior to backfilling the P4 pond, a dye test was conducted by MDNR, GSRAD/Geologic Survey Program (GSP) to determine the direction of groundwater. GSP released 1/2 gallon of Rhodamine WT dye near the middle of the P4 pond on February 25, 2002. Attempts at dye recovery from several perimeter locations were made between March and September 2002. Traces of dye were discovered but the lack of persistence at any one location suggested that the dye could have been tracked in by heavy equipment. The direction of dye movement was not established and the dye test was terminated in late 2002.

After P4 pond was backfilled, Mohawk Drilling of Tulsa, Oklahoma installed a 2-inch diameter well in July 2002. The total depth of the P4-Central well is 38 feet or approximately at the bottom of the original P4 pond. The well is screened across backfilled tailings over the interval from 18 to 38 feet. The well exhibited artesian flow until October 2002; thereafter, the water level has dropped to around 10 feet below the top of casing. Water samples are collected using a peristaltic pump. A rising head test indicated that the tailings were releasing water at a rate of 0.007 gpm.

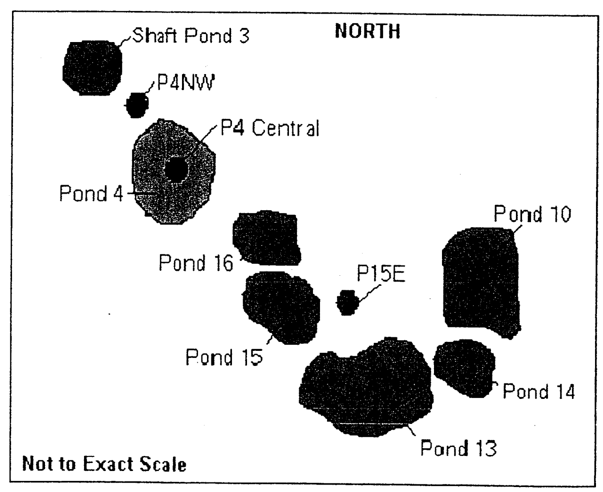

Figure 1. Sub-aqueous Disposal Site Map

6 LABORATORY RESULTS

As expected, the placement of mill tailings caused large increases in several parameter concentrations detected in P4-Central well, notably calcium (10x), iron (350x), sulfate (15x), total dissolved solids

(12x), and zinc (100x). Post-backfill sampling of the nearby ponds and wells has not, as yet, identified any parameter increases that can be confidently attributed to backfilling the subsidence pit; however, Shaft No. 3 Pond has experienced increased calcium, hardness, magnesium, manganese, sulfate, total dissolved solids, and zinc concentrations. This is based on two samples, one collected in July 2001 prior to backfilling, and one collected in the Spring of 2003. The increase may be a result of runoff recharge, or impacts from the Demonstration Site, or both. Additional sampling is planned for September 2003.

7 ZINC LOADING ESTIMATES

An estimate of zinc loading from the Demonstration Site was made using the following assumptions:

- A saturated cross-sectional area of 200 feet x 30 feet = 6,000 ft^2
- The hydraulic gradient between P4 and P16 Ponds of 0.016 (April 14, 2003).
- Permeability of in tailings of 2×10^{-7}cm/sec.
- Effective porosity of limestone of 9 percent, the high end of a range provided by Spruill (1987).
- Maximum zinc concentration of 8 mg/L in P4-Central well.

Groundwater velocity = (hydraulic conductivity/effective porosity)(hydraulic gradient)

= (2×10^{-7}cm/sec/0.09)(0.016)(conversion factor of 0.032)

= 1.1×10^{-9}ft/sec

Groundwater flux = (groundwater velocity)(cross-sectional area)

= (1.1×10^{-9} ft/sec)(6,000 ft^2)

= 6.8×10^{-6} ft^3/sec

Zinc load = zinc concentration (mg/L) x flux (ft^3/sec)

= (8 mg/L)(6.8×10^{-6} ft^3/sec)(conversion factor of 5.4)

= 2.9×10^{-4} lbs/day or 0.1 lbs/year.

The Demonstration Site zinc load estimate is negligible and probably not distinguishable from background concentrations using conventional monitoring equipment. Tests are planned to estimate hydraulic conductivity of the limestone so that pre-backfill zinc loading can be compared to the Demonstration site loads.

Runoff from 11 acres of unvegetated tailings would generate about 50 to 80 lbs of annual zinc loading, based on zinc content in runoff from chat piles in Treece, Kansas (9.7 mg/L).

If the 11-acre tailings excavation site were capped with an 18-inch simple soil cover, as described in the FS under Alternative 3, zinc loading in runoff would be somewhat less. The FS gives an estimated infiltration rate of 4.8 inches/year for a simple soil cover on tailings based on EPA's Hydrologic Evaluation of Landfill Performance (HELP) model. Using this infiltration rate yields a zinc load in runoff of about 11 lbs/year as shown below:

Annual Runoff volume = (site acreage)(4.8 inches annual runoff)

= (11 acres)(0.4 ft/year)

= 4.4 acre-ft/yr or .012 acre-ft/day or 6×10^{-3} ft^3/sec

Zinc load = zinc concentration (mg/L) x flux (ft^3/sec)

= (9.7 mg/L zinc) (6×10^{-3} ft^3/sec)(conversion factor of 5.4)

= 0.03 lbs/day or about 11 lbs/year.

8 CONCLUSION

A significant increase in zinc or other parameter concentrations in nearby ponds or wells has not been observed since post-backfill monitoring began in September of 2002.

The predicted zinc loading from the Demonstration Site is very small because of the low permeability of the tailings and host rock, and the small hydraulic gradient. The predicted zinc loading is far too small to increase zinc concentrations in the Boone aquifer, estimated to contain 4 million pounds of zinc in the Waco subdistrict alone.

In this test case, that subaqueous disposal essentially eliminated an annual zinc load of 50 to 80 lbs from the surface water system, and replaced it with an annual addition of 0.1 lb to the shallow aquifer. With time, it is expected that metals loading to the aquifer will drop to background levels once anaerobic conditions are established.

9 RECOMMENDATIONS

The following recommendations are offered for consideration if EPA Region VII identifies subaqueous disposal as the selected alternative in the Jasper County FS:

- Use pits that are hydraulically isolated from groundwater. After isolation of surface water sources, candidate ponds should be pumped down to gauge the amount and source of recharge.
- Desirable sites for mill waste disposal are subsidence pits that currently pose physical hazards, are being used as trash dumps, and/or provide only marginal aquatic habitat. The filling of some subsidence pits would eliminate physical hazards and alleviate illegal trash dumping.
- If possible, backfill tailings first to form a low-permeability "liner" in the pit.
- Tailings can be used as low-permeability cap material.
- Sample prospective fill materials, conduct saturated consolidation tests, and predict expected

settlement. Surcharge the pit with additional fill and allow time for settlement before placing the soil cap.

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