Report as of FY2007 for 2007MT188B: "Resource Recovery from Flooded Underground Mine Workings- Butte, Montana"

Publications

Project 2007MT188B has resulted in no reported publications as of FY2007.

Report Follows

Resource Recovery from Flooded Underground Mine Workings- Butte, Montana

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Introduction

Extensive mining in Butte, Montana has created a system of flooded underground mine workings. The groundwater in the Butte Historic Mining District has excessive concentrations of heavy metals and metalloids due to this past mining activity and the high sulfide mineral content of the area. The US EPA determined that it is technically impracticable to remediate this bedrock aquifer. However, there is still potential for utilizing this water in a beneficial way.

The Belmont Mine is one of several dozen vertical shafts that were constructed to access the underground mine workings. It is located near the Berkeley Pit Lake viewing stand. A past attempt was made at pumping water from the Belmont shaft for irrigation of a nearby park and a football field. However, after several weeks of continuous pumping, the concentrations of arsenic, manganese, iron, and zinc surpassed the proposed irrigation standards, and using this source of irrigation water was abandoned.

The idea of using Belmont Mine water for irrigation is now being re-visited through a new research grant to MSE-Technology Applications through EPA and DOE's Mine Waste Technology Program. The project has three facets: 1) A new pumping test of the Belmont Mine will be performed in July, 2007, up to a maximum of 45 days in duration. The rate of pumping and length of the test will be set to simulate the water needs of a full irrigation season. Major cations and anions, total recoverable metals, dissolved metals, alkalinity, iron and arsenic speciation, pH, specific conductivity, temperature, dissolved oxygen, oxidation-reduction potential, and stable isotopes of water, dissolved sulfate, and dissolved inorganic carbon will be monitored for the duration of the pumping test; 2) Bench scale and field scale experiments will be performed to test different low-cost technologies for treating the Belmont water to meet irrigation requirements. From prior data, it is expected that water treatment will need to focus on arsenic, iron, zinc, and manganese; and 3) MSE will examine the potential for using the Belmont pumping station for heating and/or air conditioning of nearby buildings.

In summary, this project has the potential to turn an aquifer that was deemed technically impracticable into a valuable resource, and affords an opportunity to learn more about the flooded underground mine workings of Butte, especially with regards to chemistry, hydrology, and interconnectivity of the mine workings in the southern portion of the district. If successful, using this water in a beneficial way will positively impact the municipal water supply and reduce the stress on the Big Hole River.

Project Objectives

1) To perform a long-term pumping test that adequately stresses the aquifer. Enough water will be pumped in order to simulate two irrigation seasons. The data collected from the long-term test will be analyzed to characterize the hydrogeologic system.
2) To collect water quality samples before, during, and after the pumping tests. These samples will be used to establish the water chemistry of the aquifer in addition to learning the maximum contaminant concentrations.
3) To test water treatment options. Several technologies will be tested to determine the best approach to treatment. Factors include feasibility, effectiveness, and footprint area.
4) To research the potential for heat recovery. The Belmont Mine water has elevated temperatures, and utilizing this resource to heat or cool nearby buildings is a possibility.
5) To collect stable isotope samples. Stable isotope samples will be analyzed in order to determine the sources of water, dissolved sulfate, and dissolved inorganic carbon in the pumped water, and to help track the changes in hydrology or geochemistry with time during the long-term pumping test.

Pumping Test Methods

A 40-horsepower pump was previously installed in a well that intercepts the working of the Belmont Mine at the 600-foot level. . Observation well #2 also intercepts the 600-foot mine workings while observation well #1 is collapsed and was used to monitor the hydrologic characteristics of the surrounding bedrock aquifer. Depth, pressure, and temperature were continually monitored in all three wells using pressure transducers throughout the pumping test. E-tape measurements of the observation wells were taken periodically as a backup depth measurement system. A flow cell in conjunction with a

YSI monitor was connected to the system to continually monitor the field parameters of specific conductivity (SC), dissolved oxygen (DO), pH, temperature, and oxidation-reduction potential (ORP).

A step draw down test was performed on July 6, 2008. The primary purpose of the step draw down test was to determine a flow rate that would sufficiently stress the aquifer during the long-term pumping test. After three well volumes were purged, four flow rates (25 gpm, 50 gpm, 100 gpm, and 140 gpm) were performed, each lasting roughly two hours. The results showed that a flow rate of 90 gpm for the long-term test would be appropriate.

The long-term test began on July 10, 2008 at a flow rate of 90 gpm. After 20 days of pumping, it was determined that the aquifer was not being sufficiently stressed, and the flow was increased to approximately 110 gpm. The long-term test continued for 9 weeks, removing approximately 8 million gallons of water from the system; the equivalent of about two irrigation seasons. Effluent water was piped to a storm drain that drains into the Berkeley Pit.

<u>Pumping Tests Results</u>

Observation well #2 and the irrigation well showed almost identical drawdown, suggesting high conductivity and connectivity of the 600-foot workings. There was approximately 60 feet of drawdown.

<u>Sampling</u>

During the step-drawdown test, primary samples were taken after three well volumes were purged, two hours after pumping began, and eight hours after pumping began. During the long-term test, most primary samples were collected every Monday, and secondary samples were collected every Friday. All samples were collected following QA/QC guidelines.

Primary sample parameters:

- major cations and anions (calcium, magnesium, sodium, potassium, sulfate, nitrate, carbonate, and chloride);
- total recoverable metals including aluminum, antimony, arsenic, barium , beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, vanadium , uranium , and zinc;

- dissolved metals including aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, vanadium, uranium, and alkalinity;
- hardness;
- total suspended solids (TSS)
- stable isotopes of water, sulfate, and carbon ; and
- Iron and arsenic speciation.

Secondary sample parameters:

- total recoverable metals including arsenic, cadmium, iron, lead, manganese, zinc;
- total dissolved metals including arsenic, cadmium, iron, lead, manganese, and zinc.
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Lab Results

Temperature

The elevated temperature of roughly 19^{o}C would be exceptional for designing a heat pump system. Other heat pump systems have been established in abandoned mines with temperatures lower than this.

Water chemistry

Belmont water is slightly acidic and very reduced. Due to a higher net acidity than net alkalinity, the water turns acidic upon oxidation. Iron, arsenic, zinc, and manganese surpassed the proposed irrigation standards after the July 6th sampling event. Since this water is being assessed for use as an irrigation source, the high sulfate concentration is also a concern because vegetation is not tolerant to high-saline water. Using Visual Minteq, it was determined that the water from the Belmont irrigation well is at equilibrium with siderite, rhodocrosite, and gypsum. Siderite and rhodocrosite are carbonate minerals that keep the water buffered at depth. Gypsum is the source for the high sulfate concentration. Table 1 shows values for field parameters and lab analysis that were collected over the duration of the pumping test.

Table 1: Preliminary data from the pumping test

Parameter	Proposed Irrigation Standards [1]	Belmont Monitoring Well– July 6, 2007	Belmont Monitoring Well– July 13, 2007	Belmont Monitoring Well– July 17, 2007	Belmont Irrigation Well– July 24, 2007	Belmont Irrigation Well– July 31, 2007	Belmont Irrigation Well– Aug. 14, 2007	Belmont Irrigation Well– Aug. 28, 2007	Belmont Irrigation Well– Sept. 5, 2007
Gallons approximate	N/A	5,000	390,000	910,000	1,800,000	2,700,000	4,960,000	7,180,000	8,100,000
pH	N/A	6.1	5.8	5.8	5.8	5.7	5.6	5.7	5.6
Specific Conductance (SC) (mS/cm)	N/A	1,915	2,608	2,644	2,704	2,731	2,604	2,944	3,079
°C	N/A	16.52	19.14	19.34	19.46	19.46	19.00	19.49	19.53
ORP [millivolts (mV)]	N/A	-70.1	19.3	58.0	-4.4	-18.7	-18.8.	-96.3	-21.0
Alkalinity [milligrams per liter (mg/L)] as CaCO3	N/A	121	Not analyzed	150	154	158	165	163	148
As (μg/L)	100 (long-term)	1,190	1,200	1,240	1,320	1,340	1,390	1,560	1,680
Cadmium (Cd) (μg/L)	10 (long-term)	Not detected	Not analyzed	0.4	0.3	0.3	0.4	Not analyzed	1.0
Fe (μg/L)	20,000 (short-term)	28,600	181,000	194,000	182,000	188,000	166,000	194,000	198,000
Lead (Pb) (μg/L)	5,000 (long-term)	0.8	Not analyzed	Not analyzed	1.7	Not analyzed	0.7	Not analyzed	1.6
Mn (μg/L)	10,000 (short-term)	4,420	24,300	23,700	21,800	21,900	17,600	Not analyzed	20,300
Zn (μg/L)	10,000 (short-term)	1,990	26,700	25,600	20,900	19,300	10,500	14,200	14,000
SO_4^{2-} (mg/L)	N/A	925	Not analyzed	1,670	1,640	Not analyzed	1,800	1,860	2,000

During pumping, most of the metal and metalloid concentrations increased during the first 8 to 10 hours of the pumping test. Figure 2 shows the concentrations of Fe, As, Mn, and Zn versus pumping time.

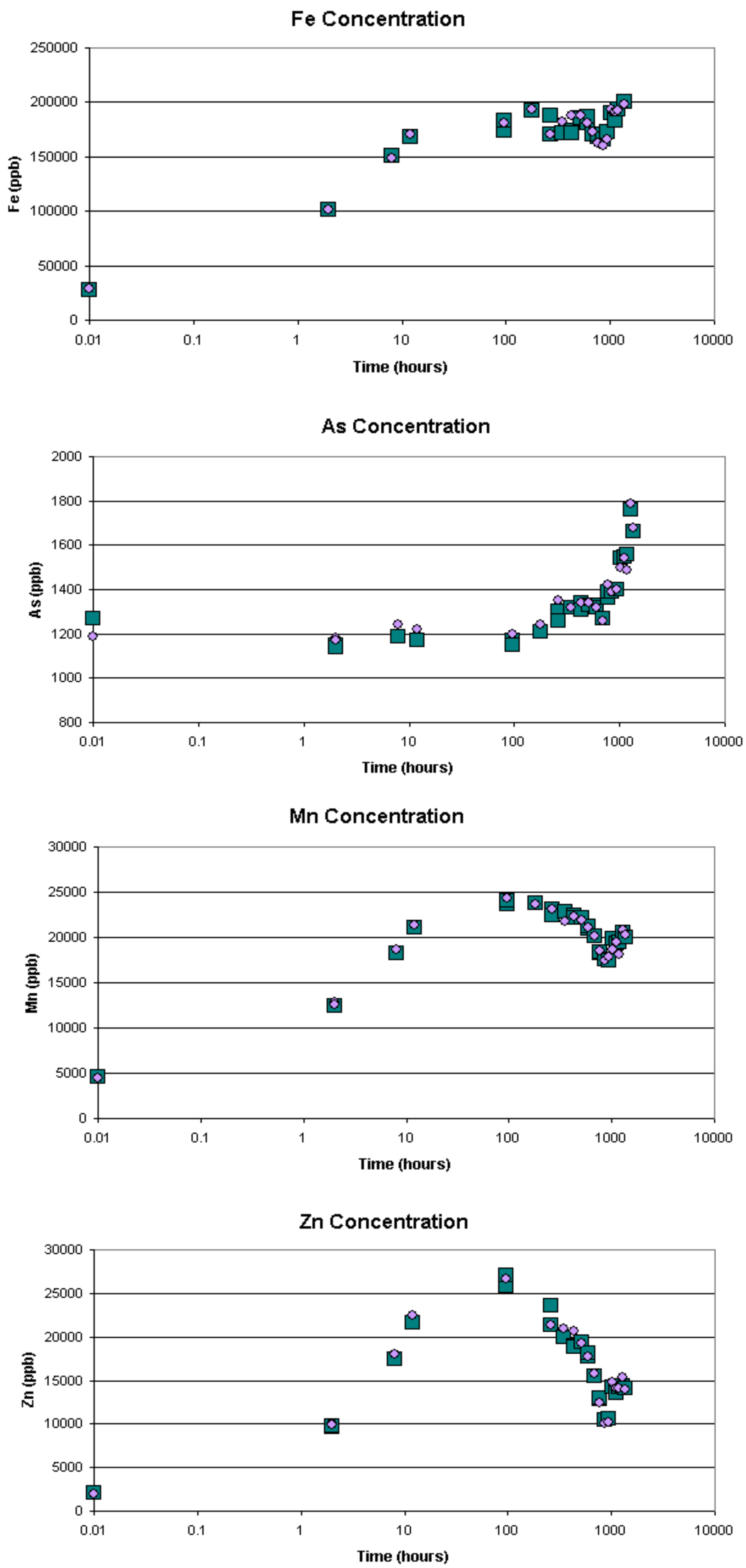

Figure 2: Concentrations vs. time

The iron is present as ferrous iron and the arsenic is present as both arsenate and arsenite. Stable isotope results suggest that the water was not being pumped from the Berkeley Pit but from the underground system of mine workings.

Treatment studies

About 100 gallons of Belmont water was collected and stored under a constant nitrogen purge for treatment testing. Phase 1 treatment tests were designed to incorporate oxidation and pH adjustment. Oxidation was prompted with either hydrogen peroxide (H_2O_2) or air. Sodium hydroxide (NaOH) was used for pH adjustment. Table 6 describes the steps involved with each test run. Head and final samples were collected; in addition, samples were collected after each step. Samples will be analyzed for Fe, As, Mn, and Zn.

Table 6: Phase 1 treatment test plan

Test Run	1st pH Stage	2nd pH Stage	Oxidation	1st Step
1	7.5	-	H_20_2	Oxidation
2	7.5	8.5	Air	NaOH
3	9.5	-	H_20_2	NaOH
4	9.5	-	Air	Oxidation
5	7.5	-	Air	Oxidation
6	9.5	10.5	Air	Oxidation
7	9.5	10.5	Air	NaOH
8	7.5	8.5	H_20_2	NaOH
9	7.5	8.5	H_20_2	Oxidation
10	9.5	-	H_20_2	Oxidation
11	9.5	10.5	H_20_2	NaOH
12	7.5	-	Air	NaOH

A second phase was performed that optimized the most favorable treatment path identified in the first phase. During phase 2, lime instead of NaOH was used for the pH adjustment and peroxide only was used to oxidize the water. A final micro-filtration step and sludge settling rates were added to test runs 17 and 18. The phase 2 samples will be analyzed for As, Zn, Mn, Fe, and total dissolved solids (TDS). Table 7 describes the sampling steps for phase 2.

Table 6: Phase 1 treatment test plan

Test Run	1st pH Stage	2nd pH Stage	Oxidation	1st Step
13	7.5	-	H_20_2	Oxidation
14	9.5	-	H_20_2	Ca $(OH)_2$
15	7.5	8.5	H_20_2	Ca $(OH)_2$
16	7.5	8.5	H_20_2	Oxidation
17	9.5	-	H_20_2	Oxidation
18	9.5	10.5	H_20_2	Ca $(OH)_2$

Once analyses are received from the lab, they will be evaluated, and the most efficient and most economical treatment will be pursued.