

**Response Action
Contract**

Contract No. 68-W-98-228



**Phase 2 Testing Results
Bunker Hill Mine Water
Treatability Study
November 2000**

URS Greiner
in association with
CH2M HILL
White Shield, Inc.

Phase 2 Testing Results Bunker Hill Mine Water Treatability Study

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1. Introduction

This report presents the methods and results for Phase 2 of the Bunker Hill Mine Water Treatability Study. A data validation summary and recommendations for full-scale mine water treatment are also provided at the end of this report.

Recommendations for Phase 2 testing were developed and presented upon completion of Phase 1 of the treatability study (CH2M HILL, 2000a,b). Phase 1 consisted of laboratory bench-scale testing of metals removal from Bunker Hill Mine water by lime-only precipitation, iron co-precipitation, lime/sulfide precipitation, and sulfide functional ion exchange. The lime/sulfide testing evaluated the insoluble sulfide “add-on” process, in which insoluble iron sulfide is added to the wastewater in a separate precipitation step after lime addition and clarification. Phase 1 also included sampling and analysis for dissolved metals of full-scale effluent from the Bunker Hill Mine Central Treatment Plant (CTP). Based on the results of Phase 1 testing, the recommendations for Phase 2 included:

- Pilot-scale testing of filtration technologies for removal of suspended solids (and associated target metals) on effluent from the Bunker Hill CTP.
- Bench-scale testing of the soluble sulfide “add-in” process for removal of dissolved cadmium (Cd), lead (Pb), and zinc (Zn) (the target metals).
- Full-scale plant trial of the soluble sulfide add-in process, coupled with pilot-scale effluent filtration, for removal of total Cd, Pb, and Zn, if the potential for achieving the project treatment goals was exhibited in the bench-scale testing.

These recommendations were addressed in Phase 2 of the treatability study, which consisted of bench-scale laboratory testing (Phase 2A), followed by pilot- and full-scale testing at the Bunker Hill Mine CTP in Kellogg, Idaho (Phase 2B).

In Phase 2A, batch testing of the soluble sulfide add-in process indicated that the project treatment goals for Cd, Pb, and Zn could potentially be met using that treatment technology. In addition, the full-scale monitoring of dissolved metals in CTP effluent in Phase 1 suggested that the target metal treatment goals could potentially be met without sulfide addition. Consequently, Phase 2B testing consisted of full-scale, continuous-flow plant trials of “lime-only” treatment and “lime+sulfide” treatment, coupled with pilot-scale filtration of a slipstream of the CTP effluent. The lime-only treatment constituted normal CTP operation, apart from using a higher pH setpoint, which was determined from the Phase 1 testing results. The lime+sulfide treatment also involved normal CTP operation and the higher pH setpoint, and used the soluble sulfide “add-in” process in which lime neutralization was followed by sodium sulfide addition. The sulfide dose was selected based on the Phase 2A lab testing results. The pilot-scale filtration technologies tested were granular media filtration (using conventional and proprietary filtration media), and cross-flow microfiltration (using polymeric and ceramic membranes).

The assumed treatment goals for target metals in Phase 2, expressed as total metal concentrations, were:

Cd - 0.5 µg/L

Pb - 3.0 µg/L

Zn - 50 µg/L

2. Phase 2A Testing

2.1 Overview and Objectives

Phase 2A testing was conducted in March 2000. Bench-scale laboratory testing was conducted to evaluate potential treatment effectiveness for removal of the target metals Cd, Pb, and Zn of the soluble sulfide add-in process, implemented at two different sulfide addition points:

- Lime/Sulfide - sulfide addition to the lime neutralization/aeration basin [after acid mine drainage (AMD)-lime contact]
- Sulfide/Lime - sulfide addition to the AMD influent pipe (before AMD-lime contact)

The first sulfide addition scenario was originally planned and described in a Phase 2 approach memorandum (CH2M HILL, 2000a); the second scenario was added to the test plan based on a subsequent conversation with Cominco about their wastewater treatment process.

The Phase 2A objectives were to:

1. Determine if the soluble sulfide add-in process could potentially meet treatment goals for removal of soluble Cd, Pb, and Zn.
2. Compare the effectiveness of the two different sulfide addition points.
3. Develop preliminary sulfide dose requirements.
4. Qualitatively assess sludge settleability and sludge production.

2.2 Materials and Methods

A 5-gallon sample of CTP influent (raw AMD prior to blending with lime and recycled sludge) was collected and shipped to CH2M HILL's Corvallis, Oregon, lab for use in treatability testing. Upon receipt at the lab, the sample was analyzed for the characterization parameters of total and dissolved Target Analyte List (TAL) metals, pH, total suspended solids (TSS), lime demand and solids formed.

The two sulfide addition treatment scenarios described above were tested. In the Lime/Sulfide scenario, lime was added to CTP influent to achieve the target pH, and then sulfide was added. In the Sulfide/Lime second scenario, sulfide was added first (at the low ambient pH of CTP influent) while the sample was vigorously mixed, to provide instantaneous and thorough contact, and then lime was added to adjust pH to the target value.

Standard jar test procedures, with slight modifications, were used. Standard jar test procedures include a rapid mix phase (with reagent addition), a slow mix phase, and a

sedimentation phase. Under both treatment scenarios, the samples were aerated during the slow mix phase to induce oxidation, as occurs in the CTP's lime neutralization/aeration basin. In the Sulfide/Lime scenario, a hand-held blender was used to vigorously mix the samples during sulfide addition, because thorough mixing was reported by Cominco to be critical to process performance.

Each scenario was tested using one target pH and two sulfide doses. A target pH of 10 was selected based on Phase 1 test results. Sulfide doses of 0.2 and 1.0 mg/L were selected based on the CTP influent sample characterization results and stoichiometric considerations. Lime-only controls (without sulfide) were tested for comparison to sulfide addition results, and a test blank (using Milli-Q water) was run to check for metals contamination. Each test condition was performed in duplicate. The test conditions are summarized on the data tables cited in the next section and located at the end of this report.

After treatment and settling, supernatant from each jar was collected, filtered through a 0.2- μm polytetrafluoroethylene (PTFE) membrane, and analyzed for dissolved Cd, Pb, and Zn. Separate supernatant samples were analyzed for turbidity, and settled sludge volume and TSS were also measured.

Detailed methods are presented in the Phase 2A Work Plan (CH2M HILL, 2000c).

2.3 Results and Discussion

The Phase 2A sample characterization data are shown in Table 1. The sulfide precipitation testing results are summarized in Tables 2 and 3. (All tables, figures, and photos are located at the end of this report.) The Phase 2A test data and observations supported the following conclusions:

- Lime/Sulfide treatment provided better Cd removal than lime-only treatment; no improvement in Pb or Zn removal was observed.
- The Lime/Sulfide treatment sequence was more effective than the Sulfide/Lime sequence.
- Increasing the sulfide dose from 0.2 to 1.0 mg/L in the Lime/Sulfide treatment enhanced Cd removal.
- The Lime/Sulfide treatment yielded dissolved concentrations of all three target metals that were less than their treatment goals.
- Liberation of Pb into solution apparently occurred at the higher sulfide dose in the Sulfide/Lime treatment.
- The lime-only treatment results were reasonably comparable to full-scale treatment performance at the CTP.
- Supernatant turbidity and sludge solids production were virtually indistinguishable between the various treatments.

- Floc that formed in the Lime/Sulfide treatment was yellow-orange in color and fairly small-sized. The Sulfide/Lime floc was brown and slightly larger. Both settled quickly and filtered relatively easily.

Based on the Phase 2A test results, Lime/Sulfide treatment (i.e., soluble sulfide add-in process with sulfide added after lime addition) at a sulfide dose of 1.0 mg S/L was recommended for full-scale testing in Phase 2B.

3. Phase 2B Testing

3.1 Overview and Objectives

Phase 2B testing was conducted in July-August 2000. Lime-only treatment, lime+sulfide treatment, and follow-up lime-only treatment full-scale trials were conducted sequentially at the Bunker Hill CTP. In conjunction with these trials, pilot-scale filtration testing was performed on a slipstream of the CTP effluent. Four different types of filtration processes were pilot-tested concurrently. During all but the initial few days of testing, the CTP effluent was spiked with solids from the clarifier underflow to roughly simulate anticipated future suspended solids loadings. Hydrokinetic Systems Inc. (HKS, Salem, Oregon) provided the pilot-scale filtration equipment used in this study, as well as operational and technical support throughout the study. CH2M HILL staff provided sulfide addition and sample collection equipment and were responsible for daily operation of the test systems, in conjunction with the Bunker Hill CTP operators.

The overall Phase 2B schedule was as follows:

June 26-30	Equipment setup, startup, and shakedown
July 8-10	Lime-only treatment <u>without</u> solids spiking of CTP effluent
July 11-27	Lime-only treatment with solids spiking of CTP effluent
July 28-August 4	Lime+sulfide treatment with solids spiking of CTP effluent
August 5-13	Shutdown to allow sulfide to flush from system
August 14-18	Follow-up lime-only treatment with solids spiking of CTP effluent
August 19	Shutdown

Phase 2B study objectives were to:

1. Assess the level of treatment achievable, in terms of effluent total Cd, Pb, and Zn concentrations, by the existing treatment system (lime-only treatment) followed by filtration.
2. Determine whether concentrations of dissolved Cd, Pb, and Zn similar to those obtained in Phase 2A lab-scale treatment could be achieved in full-scale lime+sulfide treatment.
3. Determine if the treatment goals for total Cd, Pb, and Zn could be achieved by lime-only treatment plus filtration, or by lime+sulfide treatment plus filtration.
4. Evaluate the effectiveness of different granular media filtration and cross-flow microfiltration technologies, and assess the relative ease of operations and maintenance.

3.2 Lime-Only Treatment

3.2.1 Materials and Methods

Treatment process. The lime-only treatment full-scale trial consisted of normal operation of the CTP using a pH setpoint of 9.5. Under normal CTP operation, lime is injected into a lime/solids contact reactor where solids from the thickener underflow are recycled to the head of the plant. Acid mine water (CTP influent) flows into the pipe conveying the lime/solids mixture to the lime neutralization/aeration basin. Lime addition to the lime/solids contact reactor is controlled by feedback from a pH probe at the outlet of the lime neutralization/aeration basin, to approximately maintain the pH setpoint entered into the control system. Effluent from the lime neutralization/aeration basin flows by gravity to a flocculation basin (the flocculator mechanism is not in use, but an anionic polyelectrolyte is added to the floc basin effluent trough) and then to a sludge thickener, where clarification occurs. The liquid effluent from the thickener flows by gravity to a polishing pond and then to the final discharge point.

Filter feed. For this study, a slipstream of the CTP effluent was pumped from where the thickener effluent discharges to the polishing pond to a feed tank in the filtration pilot testing area, located inside the former filtration building. The water level in the filter feed tank was maintained by a float switch that actuated a submersible pump in a bucket suspended in the thickener effluent discharge flow. During the first few days of testing, this water was used directly as filter influent. During the remainder of the study, this water was spiked with sludge solids from the thickener underflow to roughly mimic anticipated future solids loading conditions. The CTP is currently operated in low-density sludge (LDS) mode but will be run in high-density sludge (HDS) mode in the future, and HDS operation is expected to yield slightly higher effluent TSS concentrations. A target TSS concentration of 25 ± 5 mg/L was selected for the filter feed, based on results from a previous full-scale HDS trial at the Bunker Hill CTP (CH2M HILL, 1997). Sludge-spiked CTP effluent was used as filter feed throughout the balance of the study.

Solids spiking. Sludge spiking was accomplished by collecting a daily sample of thickener underflow, diluting the sludge sample to a selected solids concentration in a sludge tank, and metering diluted sludge into the sludge spiking/filter feed tank at a rate calculated to create the target TSS concentration in the filter feed. The sludge tank and filter feed tank were continuously mixed with recirculation pumps. All of the pilot filtration systems were fed from this common feed tank. When the early filter feed data results revealed that the TSS concentration was lower than intended, sludge spiking was elevated by increasing the solids concentration in the sludge tank and/or increasing the flow rate of diluted sludge to the filter feed tank.

Filtration processes. The filtration processes piloted in Phase 2B testing included both granular media filtration and microfiltration systems (Photo 1). The individual processes were:

TM1 (tri-media 1) – A conventional tri-media filter of garnet (about 0.25 mm diameter), sand (about 0.4 mm diameter), and anthracite (about 1.2 mm diameter). The TM1 filter consisted of a 6-inch-diameter clear polyvinyl chloride (PVC) pipe

(surface area = 0.196 ft²) containing approximately 4 inches of garnet, 10 inches of sand, and 16 inches of anthracite, for an overall 30-inch bed depth (Photo 2).

TM2 (tri-media 2) – A second tri-media filter, identical to TM1, that was set up late in the study and operated in parallel to TM1 for direct comparison of different operational parameters.

JC (JelCleer) – A mono-media filter of JelCleer™ 1000 (Argo Scientific, San Marcos, California), a patented granular medium of 0.26-0.33 mm plastic-coated glass beads that are “activated” by applying a high molecular weight organic coagulant (JelCoat™ 700) to the filter. This filter initially consisted of a 6-inch, clear PVC pipe (surface area = 0.196 ft²) containing 30 inches of JelCleer, but was switched to a 4-inch PVC pipe (surface area = 0.087 ft²) later in the study when the 6-inch pipe was used to test prefiltration and the influent flow rate was reduced appropriately to maintain the target flux rate for the lower surface area (see Photo 2).

PMF (polymeric microfilter) – A cross-flow microfilter using a polymeric membrane filtration medium (0.2-µm pore size polypropylene). This system had 41 5.5-mm tubes and an effective filtration area of 1.0 m² (Photo 3).

CMF (ceramic microfilter) – A cross-flow microfilter using a ceramic filtration medium. This system had seven 6.0-mm channels and an effective filtration area of 0.119 m² (see Photo 3).

The TM1, JC, PMF and CMF filter systems were tested during the initial lime-only treatment period (TM2 was set up later in the study). Additional details on the filter processes and their operation are given in the Phase 2B Work Plan (CH2M HILL, 2000d).

Test conditions. A number of process parameters were varied during the course of Phase 2B testing. These variables were intended either to challenge the treatment systems, or to improve treatment performance. The variables included increasing the TSS concentration of sludge-spiked filter feed, prefiltration using an anthracite “roughing” filter prior to the TM1 and JC filters, changing the flux rate to the granular media filters (5 or 4 gpm/ft²), adding flocculent (5 mg/L dose) to the filter feed, and changing the backwashing frequency (once or twice/day). The flocculent used was FILTERMATE CF 500 (Argo Scientific, San Marcos, California), a 20:1 mixture (by weight) of ferric sulfate and cationic polyelectrolyte.

All of these variables were not tested during the initial lime-only treatment period. Figure 1 shows the test conditions and operating schedule for this phase of the study. Solids spiking and flux rate to the TM1 and JF filters were varied during this test phase, and the granular media filters were backwashed either once or twice per day.

Sampling and analysis. Figure 2 is a schematic of the CTP and pilot filtration processes showing the eight sampling points where samples were collected for offsite lab analysis of performance monitoring parameters (primarily metals). Table 4 shows the sampling and (offsite) analysis plan for these sampling points. In addition to the analyses shown in Table 4, selected samples were analyzed for the full list of TAL metals on three dates during the study, to evaluate levels of non-target metals. Two of these dates fell within the initial lime-only treatment period, and the third was during the follow-up lime-only treatment period.

Grab samples of the CTP influent (raw AMD) were collected at location S1. Composite samples were collected at sampling points S2 through S8 using an automated system programmed to collect subsamples hourly. These subsamples were delivered to acid-washed, 1-gallon plastic cubitainers, which were used only once and replaced daily. Composite samples recovered for analysis daily were 24-hour composites except when operational changes or maintenance requirements caused the samples to be collected over only a portion of the 24-hour period.

Samples were split onsite and filtered and/or preserved as required for the different analyses. For dissolved metals, samples were filtered through a 0.45- μm PTFE membrane and the filtrates were preserved with nitric acid (HNO_3) to $\text{pH}<2$. Whole samples for total metals analysis were preserved with HNO_3 , and samples for analysis of TSS and lime demand/solids formed were cooled to 4°C . Metals analyses were performed at CH2M HILL's laboratory in Corvallis, Oregon, using EPA Contract Laboratory Program (CLP) procedures.

In addition to the offsite analyses, a variety of operations monitoring parameters were determined onsite. The onsite monitoring plan is shown in Table 5.

3.2.2 Results and Discussion

3.2.2.1 CTP Influent and pH

Cd, Pb, and Zn data for the entire study are summarized in Tables 6, 7, and 8, respectively. Table 9 summarizes TSS, lime demand and solids formed, and pH (measured by CTP operators) data for the study period. Total metals concentrations in CTP influent during the lime-only treatment period averaged $190\ \mu\text{g}/\text{L}$ for Cd, $583\ \mu\text{g}/\text{L}$ for Pb, and $111,670\ \mu\text{g}/\text{L}$ for Zn. Wastewater pH measured at the sludge thickener was usually between 9.0 and 9.5, but decreased to pH 8.2 on July 18 because of a lime pump failure at the CTP.

3.2.2.2 CTP Treatment

During lime-only treatment, total Cd levels in CTP effluent averaged $0.74\ \mu\text{g}/\text{L}$ and ranged from 0.32 to $1.7\ \mu\text{g}/\text{L}$. The average total Cd removal efficiency calculated using average CTP influent and CTP effluent values was 99.6 percent. Total Cd levels were usually less than about $0.60\ \mu\text{g}/\text{L}$, and were less than the treatment goal of $0.5\ \mu\text{g}/\text{L}$ roughly 40 percent of the time. The average value for total Cd was elevated by an upset period of relatively high concentrations. The first part of this period (July 17-19) was apparently caused by the low pH excursion mentioned above. During those three days, the total and dissolved Cd concentrations were virtually identical, suggesting that less Cd was precipitated from solution at the lower pH. (Note that although a pH of 9.2 is reported for July 17, that measurement represents a once per day grab sample, whereas the July 17 composite sample analyzed for metals was recovered on the morning of July 18, according to the standard compositing procedure.) The second part of this period (July 20-21) exhibited elevated total Cd levels but lower dissolved Cd levels, suggesting that it was a result of carryover of particulate Cd from the thickener. Pb and Zn levels also exhibited some detrimental effects during this upset period. Dissolved Cd levels in CTP effluent were normally similar to the total concentrations, averaging $0.59\ \mu\text{g}/\text{L}$ and ranging from 0.29 to $1.8\ \mu\text{g}/\text{L}$.

Total Pb levels in CTP effluent during lime-only treatment averaged 1.1 µg/L, ranged from <0.49 to 3.6 µg/L, and were less than 2.0 µg/L on all but one day (out of 18). Thus, total Pb levels were lower than the treatment goal of 3.0 µg/L more than 94 percent of the time. The average total Pb removal efficiency was 99.8 percent. Dissolved Pb concentrations averaged 0.61 µg/L and ranged from <0.49 to 1.3 µg/L.

Total Zn levels in CTP effluent during lime-only treatment averaged 199 µg/L and ranged from 83 to 400 µg/L. Zn levels were never below the treatment goal of 50 µg/L. The average total Zn removal efficiency was 99.8 percent. Dissolved Zn concentrations averaged 160 µg/L and ranged from 32 to 290 µg/L.

CTP effluent TSS concentrations averaged 3.3 mg/L and ranged from <2 to 6 mg/L during the lime-only test period.

3.2.2.3 Filter Performance

Without solids spiking. During the three days of testing without solids spiking of the filter feed, the granular media filter effluents easily met the treatment goals for all three target metals. The microfilter effluents also met the target metals treatment goals, except for Pb concentrations in the PMF and CMF effluent on one day each. The microfilter data showed evidence of sample contamination from the test system equipment, because the effluent total Pb concentrations exceeded the respective influent levels.

With solids spiking. Sludge spiking during lime-only testing resulted in the following average concentrations and ranges in the solids-spiked CTP effluent/filter feed (sampling point S3): Cd – 4.9 µg/L (2.9 to 8.3 µg/L), Pb – 13.1 µg/L (6.0 to 24.1 µg/L), Zn – 3,063 µg/L (1,910 to 5,240 µg/L). TSS averaged 17.5 mg/L and ranged from 10 to 36 mg/L. Dissolved Cd, Pb, and Zn concentrations in solids-spiked filter feed averaged 3.2, 0.51, and 1,641 µg/L, respectively. (Note that throughout this report, dissolved metal is functionally defined as what passes through a 0.45-µm PTFE membrane and is measured in the filtrate. Although this is the conventional definition for dissolved constituents, it is likely that some very fine particulate and colloidal metals may be measurable by this procedure and that it does not give an absolutely true measure of metals in solution.)

Figures 3, 4, 5 and 6 present filter performance data for Cd, Pb, Zn, and TSS, respectively, for the entire study. Figures 3 through 5 show two plots of similar data. The lower plot omits the filter feed data set and has the y-axis expanded to better illustrate differences between the individual filter effluents. In general, performance among the different types of filtration systems was fairly similar much of the time during the study, although the data exhibited some rather prominent outliers. Filter performance data and operational observations are discussed below.

Average total Cd concentrations in the four filter effluents (TM1, JC, PMF, and CMF) ranged from 0.23 to 0.33 µg/L during lime-only treatment, representing removal efficiencies of 93 to 95 percent relative to the solids-spiked filter feed. All of the average effluent Cd levels were less than the treatment goal, and all but five of the individual filter effluent values met the treatment goal. The first four of these occurred on July 17-18 and can be attributed to the low pH excursion in the CTP (when higher Cd concentrations remained in solution). Cd was slightly elevated in PMF effluent on July 17 and effluent Cd levels were elevated in all

three of the filter systems operating on July 18. The fifth high Cd level appeared in the TM1 filter effluent on July 23. On that date, the solids-spiked filter feed contained the highest TSS concentration of the entire study, and it seems likely that solids breakthrough was responsible for this elevated Cd concentration. Onsite measurements showed that the TM1 effluent turbidity increased from 0.1 nephelometric turbidity units (NTU) after about 4.5 hours of operation to an extremely high 16.6 NTU after 15.5 hours. For comparison, turbidity in the JC effluent, which did not have a substantially elevated Cd concentration on that date, increased from 0.1 NTU to only 4.0 NTU over the same period (a significant increase but much less than for TM1). Using a lower flux rate, more frequent backwashing, or flocculent addition can often reduce the occurrence or severity of solids breakthrough. Cd removal performance was very similar between the TM1 and JC filters. The difference in their average effluent Cd levels can be attributed to the different performance on one day (July 23).

Pb concentrations in all filter effluents were typically near or below the instrument detection limit (IDL) of 0.49 µg/L, and easily less than the treatment goal except for a few isolated, anomalously high spikes (at least some of which could be a result of sample contamination). During the lime-only with solids spiking test period, filter effluent Pb concentrations averaged from 0.56 to 0.75 µg/L, representing average removal efficiencies of 94 to 96 percent across the filters. There was only one instance when a filter effluent Pb concentration exceeded the treatment goal; that was the TM1 effluent on July 23, when solids breakthrough was apparent, as discussed above. As with Cd, filter performance for Pb was comparable between the TM1 and JC filters, with the July 23 data accounting for the difference in average effluent Pb levels.

Zn concentrations in the filter effluents averaged from 19.3 to 37 µg/L (excluding data from July 23), representing average removal efficiencies of 99 percent. These average effluent values were less than the treatment goal. Individual Zn levels exceeded the treatment goal on five separate occasions. Three of these were associated with the high solids loading on July 23 (TM1 effluent on July 23 and 24, and JC effluent on July 23). The other two elevated Zn incidents occurred in JC effluent shortly thereafter, on July 25 and 27. The onsite turbidity measurements for JC effluent on those dates (0.08-0.15 NTU) were not indicative of excessive solids breakthrough, so the cause of the higher Zn levels is not apparent. (Note that the microfilters were not online during these periods.) Filter performance was usually comparable between the TM1 and JC filters. Filtration performance for Zn fared worse in TM1 than JC because of solids breakthrough on July 23, but the JC filter experienced more days of reduced performance.

TSS concentrations in filter effluents averaged from 3 to 4 mg/L.

The flux or surface loading rate to granular media filters TM1 and JC was reduced from 5 to 4 gpm/ft² on just the last two days of this testing period. Therefore, it is difficult to evaluate whether filtration performance was improved based on this small data set. Effluent levels of Cd and Pb at the 4 gpm/ft² flux were as low or lower than at the higher flux. Zn levels were also relatively low in three out of four effluent samples at the lower rate, but one sample was the unexplained elevated Zn spike observed for JC effluent on July 27.

Both microfilter systems experienced severe fouling problems, which resulted in high effluent pressure loss and reduced flux. The CMF system required shutdown for cleaning on

the third and ninth days of operation, and was taken offline on July 17. Similarly, the PMF system required shutdown and cleaning on the fourth and fourteenth days of operation, and was taken offline on July 23. Aggressive cleaning was required to re-establish the original flux rate. HKS staff have suggested that the fouling problems might be caused by the polymer used to enhance sludge settling in the CTP. The frequency of shutdown/cleaning requirements indicates that the use of microfiltration at Bunker Hill would entail excessive maintenance time and cost.

Table 10 presents the Phase 2B TAL metals data. Samples were analyzed for TAL metals on two dates during the lime-only treatment period (July 16 and 25). These results show that concentrations of mercury and silver (other possible metals of concern) in filter effluents were very low (0.02 µg/L or less and <2.6 µg/L, respectively). Also, the high concentrations of calcium and magnesium result in elevated water hardness, which mitigates the aquatic toxicity of many metals.

3.3 Lime+Sulfide Treatment

3.3.1 Materials and Methods

Treatment process. The lime+sulfide treatment full-scale trial consisted of normal operation of the CTP with a pH setpoint of 9.5, and addition of sulfide to the flocculation basin effluent trough. The target sulfide dose was 1 mg S/L. Sulfide solution added at this location mixed with wastewater flowing along the trough and received further mixing as the water traveled through the pipe running from the flocculation basin to the center well of the sludge thickener.

Sulfide addition. Sulfide stock solution (approximately 50 g S/L) was prepared in batches from sodium sulfide (Na₂S, 61.2 percent, or 25.1 percent S) and tap water. Batches were made up daily, the amount of mixing was minimized, and the tank was covered to avoid excessive oxidation during preparation and storage. The stock solution feed rate was keyed to the daily wastewater flow rate through the CTP to maintain the target dose. The sulfide addition system consisted of a sulfide stock solution tank, mixer, feed pump, and flexible tubing run from the sulfide solution tank to the floc basin effluent trough (Photo 4). An injection structure (PVC pipe with drilled holes) was initially used to distribute the sulfide solution across the effluent trough, but this was discarded when the small outlet holes became plugged.

Filtration processes. All five filtration systems described previously were tested during the lime+sulfide treatment period.

Test conditions. Figure 6 shows the test conditions and operating schedule for the lime+sulfide treatment period. Variables tested during this phase of the study were flux rate, flocculent addition, and prefiltration using an anthracite roughing filter before the TM1 and JC filters. The elevated level of filter feed sludge spiking was used throughout the period. The granular media filters were backwashed once per day.

Filter feed, solids spiking, sampling and analysis. All were as described under Subsection 3.2.1, Lime-Only Treatment.

3.3.2 Results and Discussion

3.3.2.1 CTP Influent and pH

Only one sample of CTP influent was analyzed for target metals during the lime+sulfide treatment period. The measured concentrations of total metals were 159 µg/L for Cd, 591 µg/L for Pb, and 100,000 µg/L for Zn. The Cd value is 16 percent less than the average for the initial lime-only test period. Cd concentrations in CTP influent tended to decrease over the course of the study. The Pb value is within approximately 1 percent of the initial lime-only test period average, and Pb concentrations remained fairly stable over the study. The Zn value is 10 percent less than that for the initial lime-only treatment period, and showed a slight decrease over time. Wastewater pH measured at the sludge thickener was between 8.9 and 9.5 during lime+sulfide treatment.

3.3.2.2 CTP Treatment

During lime+sulfide treatment, total Cd levels in CTP effluent averaged 0.32 µg/L and ranged from 0.21 to 0.42 µg/L. The average total Cd removal efficiency calculated using the single CTP influent value and the average CTP effluent value was 99.8 percent. Total Cd levels were consistently less than the treatment goal of 0.5 µg/L. Dissolved Cd levels in CTP effluent were similar to the total concentrations, averaging 0.28 µg/L and ranging from 0.19 to 0.35 µg/L. No CTP upsets occurred during lime+sulfide treatment. If the apparent upset conditions during lime-only treatment are ignored, lime+sulfide treatment produced an average total Cd concentration in CTP effluent that was about 30 percent lower than lime-only treatment (the average for the initial lime-only treatment period was 0.46 µg/L if the data from July 17-21 are omitted).

Total Pb levels in CTP effluent during lime+sulfide treatment averaged 0.78 µg/L and ranged from 0.57 to 0.88 µg/L. Thus, total Pb levels were consistently lower than the treatment goal of 3.0 µg/L. The average total Pb removal efficiency was 99.9 percent. Dissolved Pb concentrations averaged 0.53 µg/L and were <0.49 in all but one sample (0.78 µg/L). Pb treatment appeared to be comparable between lime+sulfide and lime-only testing, especially if elevated levels during apparent upset conditions from July 17-21 are ignored.

Total Zn levels in CTP effluent during lime+sulfide treatment averaged 170 µg/L and ranged from 108 to 223 µg/L. Zn levels were never below the treatment goal of 50 µg/L. The average total Zn removal efficiency was 99.8 percent. Dissolved Zn concentrations averaged 152 µg/L and ranged from 97 to 197 µg/L. Lime+sulfide and lime-only treatment were fairly comparable in reducing Zn concentrations.

CTP effluent TSS concentrations averaged 5.5 mg/L and ranged from 2 to 7 mg/L during the lime+sulfide test period.

3.3.2.3 Filter Performance

Sludge spiking during lime+sulfide testing resulted in the following average concentrations and ranges in the solids-spiked CTP effluent/filter feed: Cd – 5.5 µg/L (4.3 to 6.3 µg/L), Pb – 15.7 µg/L (8.7 to 18.9 µg/L), Zn – 3,873 µg/L (2,590 to 5,220 µg/L). TSS averaged 25.3 mg/L and ranged from 17 to 35 mg/L. Dissolved Cd, Pb, and Zn concentrations in solids-spiked filter feed averaged 3.5, 0.54, and 2,021 µg/L, respectively. The metals and

suspended solids concentrations during lime+sulfide filter feed were fairly comparable to levels in the latter half of the initial lime-only treatment period, which used higher sludge spiking. The filter feed levels also tended to be more consistent during Lime+sulfide testing. Filter performance data and operational observations are discussed below.

Average total Cd concentrations in the five filter effluents (TM1, JC, PMF, CMF, and TM2) ranged from 0.05 to 0.12 µg/L during lime+sulfide treatment, representing removal efficiencies of 98 to 99 percent relative to the solids-spiked filter feed. All of the average and individual effluent Cd levels were well below the treatment goal. During lime+sulfide treatment, the JC filter performed slightly better than the tri-media filters, although both types performed well. The microfilters also produced very low effluent Cd concentrations. In general, lower Cd concentrations were shown to be achievable by filtration following lime+sulfide treatment than lime-only treatment.

During lime+sulfide treatment, filter effluent Pb concentrations averaged about 0.50 µg/L for the granular media filters (TM1, TM2, and JC), representing average removal efficiencies of 97 percent across the filters. Pb concentrations in these filter effluents were typically near or below the IDL of 0.49 µg/L, and all were substantially less than the treatment goal. Treatment performance for Pb was virtually identical between the tri-media and JC filters. The microfilter (PMF and CMF) effluent data were similar except for anomalously high Pb concentrations measured for both systems on July 28, one of which (CMF) was greater than the treatment goal. Treatment performance was similar to that for lime-only treatment, but slightly better for lime+sulfide in the consistency of low Pb levels achieved.

Zn concentrations in the filter effluents averaged from 21.0 to 30.7 µg/L, representing average removal efficiencies greater than 99 percent. All of the average effluent values and all but one of the individual effluent values (JC effluent on July 28) were less than the treatment goal. TM1 and JC filter performance were comparable; the higher JC average is skewed by that one high value. Zn removal in TM1 during lime+sulfide treatment was comparable to that achieved by lime-only treatment when it was not affected by solids breakthrough (July 23).

TSS concentrations in filter effluents averaged from 4 to 5 mg/L.

Test conditions that varied during lime+sulfide treatment include prefiltration, flux rate, and flocculent addition. Without a sustained period of testing it is difficult to assess the effects of these variables on treatment performance. Prefiltration through an anthracite roughing filter did not appear to be beneficial, based on visual observation of solids infiltration in the granular media filters (this was particularly easy to observe in the translucent JC media). The data do not support definitive conclusions about flux rate or flocculent effects, but filter performance in TM1, JC, and TM2 appeared to be as good or perhaps slightly better during use of the lower flux rate (4 gpm/ft²) and/or flocculent addition.

3.4 Follow-up Lime-Only Treatment

This follow-up testing was conducted because initial testing of this treatment process indicated that the project treatment goals could be met by lime-only treatment coupled with tri-media filtration, as long as pH excursions and solids breakthrough are avoided. This test

phase was intended to confirm those findings. In general, testing had shown that tri-media filtration was able to produce effluent quality comparable to the other filtration systems. Also, tri-media filtration is probably the least expensive, easiest to operate and maintain, and most widely-used of the filtration technologies tested.

3.4.1 Materials and Methods

Treatment process. The lime-only treatment process during this test period was identical to the initial lime-only trial.

Filtration processes. Only the TM1 and TM2 filtration systems were tested during the follow-up lime-only treatment period.

Test conditions. Figure 7 shows the test conditions and operating schedule for the follow-up lime-only treatment period. A flux rate of 4 gpm/ft² was used for both of the tri-media filters. Flocculent was added to the influent of TM1 but not TM2. The elevated level of filter feed sludge spiking was used throughout the period. The granular media filters were backwashed either once or twice per day.

Filter feed, solids spiking, sampling and analysis. All were as described under subsection 3.2.1, Lime-Only Treatment.

3.4.2 Results and Discussion

3.4.2.1 CTP Influent and pH

Only one sample of CTP influent was analyzed for target metals during the follow-up lime-only treatment period. The measured concentrations of total metals were 142 µg/L for Cd, 574 µg/L for Pb, and 93,000 µg/L for Zn. The Cd and Zn values were slightly lower than in the previous test periods, whereas the Pb concentration was comparable to earlier levels. Wastewater pH measured at the sludge thickener was consistently 9.3 during follow-up lime-only treatment.

3.4.2.2 CTP Treatment

During follow-up lime-only treatment, total metals in CTP effluent averaged 0.30 µg/L for Cd, <0.54 µg/L for Pb, and 73.2 µg/L for Zn, representing average removal efficiencies of 99.8 percent, 99.9 percent, and 99.9 percent, respectively. All individual Cd and Pb concentrations in CTP effluent were less than the treatment goals, whereas all Zn values were slightly above the treatment goal. The total and dissolved concentrations of target metals in CTP effluent were quite consistent during this period of testing. CTP effluent total Cd levels were similar to those from the lime+sulfide treatment, whereas total Pb and Zn levels were lower than in lime+sulfide treatment. TSS concentrations averaged 2.4 mg/L, which was less than half the average concentration during lime+sulfide treatment.

3.4.2.3 Filter Performance

Sludge spiking during follow-up lime-only testing resulted in the following average total metal concentrations in the solids-spiked CTP effluent/filter feed: 4.2 µg/L for Cd, 15.0 µg/L for Pb, and 2,942 µg/L for Zn (the daily values were relatively consistent). TSS averaged 19.6 mg/L and ranged from 15 to 22 mg/L. The filter feed Cd, Zn, and suspended

solids concentrations during follow-up lime-only were slightly lower than in lime+sulfide treatment, while Pb levels were similar.

All Cd concentrations in filter effluent (TM1 and TM2) were consistently less than the treatment goal (averages were 0.18 and 0.20 µg/L).

All filter effluent Pb concentrations were less than the treatment goal, and all but one value (TM1 on August 15) were less than the IDL of 0.49 µg/L. The Pb concentration was relatively high, but less than the treatment goal, in TM1 effluent on August 15. Turbidity measurements did not indicate solids breakthrough in TM1 effluent on that date, so no explanation is apparent for the elevated Pb value. Sample contamination is suspected. Pb removal during follow-up lime-only treatment was comparable to that achieved in lime+sulfide treatment.

All TM1 effluent Zn levels were less than the treatment goal. Zn exceeded the treatment goal in TM2 effluent on one occasion. In TM2 effluent, Zn was elevated but less than the treatment goal on August 15, and levels slightly exceeded the treatment goal on August 16. A review of the onsite turbidity data indicates some breakthrough of solids through the TM2 filter on both August 15 and 16 (effluent turbidity increased from a typical value of about 0.10 NTU to elevated values of 1.20 and 1.74 NTU before the end of the sample compositing period on the August 15 and 16 sample dates, respectively). On August 17-18, the two filters were backwashed twice per day rather than once per day, and no elevated turbidity or Zn levels were observed. Zn treatment was comparable to the performance of lime+sulfide treatment.

The only operational difference between TM1 and TM2 during follow-up lime-only testing was that TM1 received flocculent addition. It is difficult to judge the effect of flocculent on treatment performance, except that TM1 did not exhibit solids breakthrough or elevated Zn levels when TM2 did, so flocculation may have enhanced filter performance for Zn. Cd and Pb data were virtually identical for the two filter effluents, if the one elevated Pb value is assumed to be attributable to sample contamination and is ignored.

Table 10 shows TAL metals data for the August 15 TM1 and TM2 filter effluents. These results were similar to those for earlier samples analyzed for TAL metals in that mercury and silver metals were low and water hardness (calcium and magnesium) was high.

4. Data Quality Review

This section summarizes the analytical and quality assurance methodology implemented for treatability analyses, and provides data review/validation findings.

Sample treatability analyses for Phase 2 were carried out by inductively coupled plasma optical emission spectroscopy (ICP, EPA 6010) for Zn, and graphite furnace atomic absorption spectroscopy (GFAA, EPA 7000 series) for cadmium and lead. Per evaluations of Phase 1 data, the ICP and GFAA methodologies were found to be optimal for Phase 2 analyses. Phase 1 findings have shown that data obtained by ICP (EPA 6010) and GFAA (EPA 7000 series) meet Phase 2 project needs with regard to detection levels and quality. Additionally, when compared to ICP/mass spectrometry (ICP/MS), the combination of ICP and GFAA provides for better quality monitoring than ICP/MS because it has better established protocols (such as CLP) for monitoring data quality. Thus, after review and input from project team and decisionmakers, Phase 2 treatability analyses were carried out by ICP and GFAA using EPA 6010/7000 series/CLP methodology, which is approved methodology for monitoring effluents.

The quality control procedures, the level of effort (frequency of quality control runs), quality control limits, corrective action requirements, and documentation requirements have been detailed for each method in the *Bunker Hill Mine Water Treatability Study Work Plan* (CH2M HILL, 1999). To provide for data of known quality and comparability between different episodes, the overall level of effort was equivalent to EPA CLP methodology (EPA ILM 4.0).

Data have been reviewed outside the laboratories by project chemists per criteria identified in the work plan referenced above and per EPA functional guidelines (USEPA, 1994 and 1999). The review has been documented in analytical batch-specific reports in project files. The flags resulting from this review have been entered in the Phase 2B metals data tables included in this report (Tables 6, 7, and 8), and the findings are summarized below.

ICP EPA 6010 zinc analyses: All sample analyses were found to meet project specifications. Some data were flagged because of Zn contamination noted in laboratory blanks. The level of contamination was below levels specified for corrective action; therefore, the laboratory did not re-run samples. Sample concentrations up to 5 times the level noted in the associated blank have been flagged as non-detect (U) per the EPA functional guidelines referenced above; 'U' flags resulting from data review have been referenced in Tables 6, 7, and 8.

Graphite furnace EPA 7000 series cadmium and lead analyses: All sample analyses were carried out per project specifications. As for Zn above, some 'U' data flags per blank results were added and have been referenced in the appended tables. The cadmium laboratory blank contamination, as for Zn, was not at levels that required re-analysis. Additionally, some cadmium and lead data have been flagged 'J' for sample matrix effects as indicated by recovery and duplicate measurements of spiked samples. These flags (see Tables 6, 7, and 8) are few and, as is detailed in sample-specific data validation reports, the recovery and relative percent deviation values do not indicate a significant impact on project decisions.

Also related to matrix effects, the laboratory has added the 'W' flags per CLP analytical spikes, as can also be seen on Tables 6, 7, and 8. These graphite furnace analytical spike recoveries are above 80 percent with the exception of a few samples at values not expected to affect project decisions. Overall matrix effects noted by both W and J flags (see Tables 6, 7, and 8) and detailed in validation reports are not expected to have a significant effect on project decisions.

Overall data quality assessment: Treatability data for Phase 2, when evaluated in terms of precision, accuracy, representativeness, comparability and completeness (PARCC) parameters, are found to meet and exceed project quality needs/targets. Overall completeness is found to be over 95 percent.

5. Summary and Recommendations

5.1 Summary and Conclusions

Phase 2 of the Bunker Hill Mine Water Treatability Study consisted of laboratory bench-scale testing (Phase 2A) followed by full-scale plant trials with pilot-scale filtration testing at the Bunker Hill CTP (Phase 2B). In Phase 2A, the soluble sulfide “add-in” process was tested on Bunker Hill Mine water, including two treatment sequences (Lime/Sulfide and Sulfide/Lime), representing two different sulfide addition points in the treatment system. Phase 2B testing included full-scale plant trials of lime-only treatment and lime+sulfide treatment. Lime-only treatment was essentially identical to current operations, except that a higher pH setpoint (pH 9.5), selected from Phase 1 treatability testing results, was used. Lime-only treatment was tested in two separate trial periods (before and after lime+sulfide treatment) for confirmation. Lime + sulfide treatment consisted of normal CTP operation, except at the high pH setpoint, and addition of sulfide to the effluent trough of the flocculation basin (prior to the sludge thickener).

Each of the full-scale trials was performed in conjunction with pilot-testing of filtration technologies on a slipstream of the CTP effluent. Four filtration technologies were tested: tri-media (TM1 and TM2), JelCleer (JC), polymeric microfiltration (PMF), and ceramic microfiltration (CMF). Throughout nearly the entire study period, CTP effluent used as the filter feed (influent) was spiked with sludge solids to approximate the higher solids loading expected to occur in the future when the CTP is operated in HDS mode.

The Phase 2 test results support the following conclusions:

Phase 2A

- Lime/Sulfide treatment provided better Cd removal than lime-only treatment, but exhibited no improvement in Pb or Zn removal.
- The Lime/Sulfide treatment sequence was more effective than the Sulfide/Lime sequence.
- A sulfide dose of 1.0 mg/L in the Lime/Sulfide sequence provided higher Cd removal than the 0.2 mg/L dose.
- The Lime/Sulfide treatment yielded dissolved concentrations of all three target metals less than their treatment goals.

Phase 2B – Full-scale CTP Treatment Without Filtration

- CTP influent contained 142-216 µg/L of Cd, 574-635 µg/L of Pb, and 93,000-113,000 µg/L of Zn. Full-scale lime-only treatment, without filtration, met the treatment goal for Cd (0.50 µg/L) about 40 percent of the time during initial lime-only testing and 100 percent of the time during follow-up lime-only testing. Some operational problems occurred during the initial lime-only testing, which accounted, at least in part, for the

poorer Cd removal performance in that trial. The wastewater pH decreased to pH 8.2 when a lime pump failed, and reduced treatment efficiency for all three target metals persisted for a few days after the pH excursion. Pb was generally easier to treat effectively and the Pb treatment goal (3.0 µg/L) was met 97 percent of the time (all but one sample out of 23). The Zn treatment goal (50 µg/L) was never met by lime-only treatment without filtration. Filtration was required to meet the Zn limit.

- Full-scale lime+sulfide treatment, without filtration, met the treatment goals for Cd and Pb 100 percent of the time, but never met the treatment goal for Zn. Except for the upset conditions during the initial lime-only trial, little or no difference was discernable between CTP effluent concentrations for target metals between lime-only and lime+sulfide treatment, without filtration.

Phase 2B – Pilot-scale Filter Performance

- Spiking of CTP effluent with sludge solids resulted in total metals concentrations averaging 4.2-5.5 µg/L of Cd, 13.1-15.7 µg/L of Pb, and 75-200 µg/L of Zn in the filter feed. Pilot-scale filtration met the Cd treatment goal 95 percent of the time (90 out of 95 samples). The failures could be attributed either to the low pH excursion in the CTP (four instances), or to solids overloading and breakthrough of the filter (one instance). Filter effluents met the Pb treatment goal 95 percent of the time. At least some of the Pb failures appeared to be a result of sample contamination and were unrelated to treatability. Filter effluent met the Zn treatment goal 93 percent of the time, and some failures were related to solids breakthrough. The problems leading to exceedances are potentially controllable through reducing flux rates, increasing backwash frequency, or adding flocculent.
- Overall, the pilot-scale filters effectively removed target metals and performance was similar between the different filter systems. Their ability to achieve effluent concentrations of target metals less than treatment goals was well-demonstrated. Lime+sulfide treatment resulted in lower Cd levels in filtered effluent than lime-only treatment, but did not improve Pb or Zn removal (in agreement with Phase 2A results). The JC, PMF, and CMF filters achieved somewhat lower effluent Cd levels during lime+sulfide treatment, but otherwise the TM filter performance was comparable to the other filtration systems. Microfilter (PMF and CMF) operation suffered greatly from reduced pressure and flux because of media fouling. The resulting requirements for regular shutdown and cleaning indicate that substantial operations and maintenance labor and cost would be associated with the use of microfiltration.

5.2 Recommendations

Based on the results of the Phase 2B full-scale trials and pilot testing, the treatment sequence recommended for mine water treatment at Bunker Hill is lime-only treatment using a pH of 9.5 followed by tri-media filtration. Testing demonstrated the ability of this treatment sequence to meet the treatment goals. Tri-media filtration is widely used, relatively easy to operate and maintain, relatively inexpensive (compared to other filtration processes), and it provided comparable performance to the other filtration processes tested. It is recommended that the tri-media filters be designed for a more conservative flux rate of

4 gpm/ft², and that they be backwashed at least every 12 hours, or as needed to prevent solids breakthrough (rather than basing backwash frequency on a critical pressure drop as normally done).

Lime+sulfide treatment showed promise for achieving even lower Cd levels, and flocculent addition to filter feed may provide enhanced removal of solids and Zn. The Phase 2B results indicate that treatment goals can be met without these treatment refinements. Therefore, they are not included in the current recommendations, but should be reserved for future consideration if additional removal of Cd and Zn is necessary. If warranted, these refinements could be implemented as retrofit processes to the refurbished CTP.

6. References

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CH2M HILL, 2000d. Bunker Hill Mine Water Treatability Study, Phase 2B Work Plan. Technical memorandum from Gary Hickman, Jim Stefanoff/CH2M HILL, and Doug Hagen/HKS to Mary Kay Voytilla/U.S. EPA, July 25, 2000.

U.S. EPA, 1994 and 1999. USEPA Contract Laboratory Program, National Functional Guidelines for Inorganic Data Review.

Table 1

Phase 2A Characterization Data^a

Metal	Units	CTP Influent (1)		CTP Influent (2)	
		Total	Dissolved ^b	Total	Dissolved ^b
General Chemistry					
pH	pH units	3.1			
TSS	mg/L	144			
Lime Demand	lbs/kgal	5.67			
Solids Formed	lbs/kgal	6.43			
Metals					
Aluminum, Al	µg/L	1980		1930	1890
Antimony, Sb	µg/L	2.1 U		2.1 U	2.1 U
Arsenic, As	µg/L	62.9		7.7 B	9.4 B
Barium, Ba	µg/L	18.8 B		16.8 B	16.6 B
Beryllium, Be	µg/L	0.48 B		0.61 B	0.70 B
Cadmium, Cd	µg/L	113		118	113
Calcium, Ca	µg/L	229000		225000	228000
Chromium, Cr	µg/L	36.7		40.0	39.2
Cobalt, Co	µg/L	174		178	173
Copper, Cu	µg/L	101		97.0	97.5
Iron, Fe	µg/L	149000		79500	79200
Lead, Pb	µg/L	702		672	646
Magnesium, Mg	µg/L	236000		232000	235000
Manganese, Mn	µg/L	202000		197000	197000
Nickel, Ni	µg/L	131		106	113
Potassium, K	µg/L	9770 B		9680 B	9770 B
Selenium, Se	µg/L	125		131	121
Silver, Ag	µg/L	29.4		24.0	24.7
Sodium, Na	µg/L	2510 B		2690 B	2530 B
Thallium, Tl	µg/L	137		146	148
Vanadium, V	µg/L	0.43 U		0.43 U	0.43 U
Zinc, Zn	µg/L	75500		75700	75700

Notes:

^a Sample of raw AMD collected at discharge to the "lined pond" and used in lab treatability testing. Two subsamples were analyzed for dissolved TAL metals.

^b Filtered through 0.45-µm PTFE membrane, then digested. Analyzed by ICP.

U = not detected above given IDL

B = CRDL > reported value > IDL

Table 2
Phase 2A Sulfide Precipitation Data - Metals

Sample description and test conditions				Dissolved metal concentration [mg/L] ^a				
General	Jar no.	S ²⁻ Dose ^b	pH	Cd		Pb		Zn
Untreated	N/A	0	3.1	113		672		75700
Lime/Sulfide ^c	Jar 1	0.2	10	0.30		0.32	UW	16.9
Lime/Sulfide ^c	Jar 2	0.2	10	0.10	W	0.32	UW	13.8
Lime/Sulfide ^c	Jar 3	1.0	10	0.06	W	0.32	UW	12.2
Lime/Sulfide ^c	Jar 4	1.0	10	0.07	W	0.32	UW	14.7
Lime-only	Jar 5	0	10	0.77	W	0.32	UW	12.5
Lime-only	Jar 6	0	10	0.68	W	0.32	UW	16.3
Sulfide/Lime ^d	Jar 7	0.2	10	0.47		0.32	UW	23.1
Sulfide/Lime ^d	Jar 8	0.2	10	0.54	W	0.32	UW	14.3
Sulfide/Lime ^d	Jar 9	1.0	10	0.47	W	4.0		12.4
Sulfide/Lime ^d	Jar 10	1.0	10	0.56	W	4.2		20.5
Water only	Test blank	0	N/A	0.05	W	0.32	U	1.3 U

Notes:

^a Samples filtered through 0.2-µm PTFE membrane, then digested. Cd and Pb analyzed by GFAA; Zn analyzed by ICP

^b mg S/L, added as Na₂S solution

^c Sulfide added after lime

^d Sulfide added before lime

U = not detected above given IDL

B qualifiers (CRDL>value>IDL) are not shown because the CLP CRDLs are much greater than levels of interest to this project

W = Post-digestion spike for GFAA is outside control limits (85-115%), while sample absorbance is <50% of spike absorbance

Table 3**Phase 2A Sulfide Precipitation Data - Supernatant Turbidity and Sludge Solids**

Sample description and test conditions				Supernatant Turbidity [ntu]	Settled Sludge		Sludge Prod. [g/L treated]
General	Jar no.	S ²⁻ Dose ^b	pH		Vol. [mL/L]	TSS [mg/L]	
Lime/Sulfide ^c	Jar 1	0.2	10	4.2	137	6230	0.854
Lime/Sulfide ^c	Jar 2	0.2	10	3.1	187	4770	0.892
Lime/Sulfide ^c	Jar 3	1.0	10	3.7	150	5780	0.867
Lime/Sulfide ^c	Jar 4	1.0	10	3.0	154	5670	0.873
Lime-only	Jar 5	0	10	2.0	143	6250	0.894
Lime-only	Jar 6	0	10	4.4	131	6800	0.891
Sulfide/Lime ^d	Jar 7	0.2	10	4.5	148	6030	0.892
Sulfide/Lime ^d	Jar 8	0.2	10	2.4	134	6530	0.875
Sulfide/Lime ^d	Jar 9	1.0	10	4.2	129	6700	0.864
Sulfide/Lime ^d	Jar 10	1.0	10	2.5	123	7070	0.870

Notes:^b mg S/L, added as Na₂S solution^c Sulfide added after lime^d Sulfide added before lime

TABLE 4
 Sampling and Analysis Plan for Offsite Laboratory Analysis

Sampling Point	Sample Description	Sample Type	Analytes	Frequency
S1	AMD (CTP influent)	grab	Cd, Pb, Zn (total) Lime demand/solids formed	1/week
S2	CTP effluent	composite	Cd, Pb, Zn (total) Cd, Pb, Zn (dissolved) TSS	1/day
S3	Filter feed (sludge- spiked CTP effluent)	composite	Cd, Pb, Zn (total) Cd, Pb, Zn (dissolved) TSS	1/day
S4	TM1 filter effluent	composite	Cd, Pb, Zn (total) TSS	1/day
S5	JC filter effluent	composite	Cd, Pb, Zn (total) TSS	1/day
S6	PMF effluent	composite	Cd, Pb, Zn (total) TSS ^a	1/day
S7	CMF effluent	composite	Cd, Pb, Zn (total) TSS ^a	1/day
S8 ^a	TM2 filter effluent	composite	Cd, Pb, Zn (total) TSS	1/day

^a Added to program midway through study

TABLE 5
Operations Monitoring Plan for Onsite Measurements

Parameter	Location	Method	Average Frequency
Temperature	CTP Effluent	Thermometer	Every 4 hr during daytime – 4 /day
	Filter Feed		
pH	CTP Influent	pH meter	1/day
	CTP Effluent (at Outfall 006)		
	CTP Thickener		
	CTP Effluent		
	Filter Feed		
TDS	CTP Effluent	Myron L Company EP Meter	4/day
	Filter Feed		
Turbidity	CTP Effluent (at Outfall 006)	Turbidimeter	1-3 /day
	CTP Thickener		
	CTP Effluent	HACH 2100P Turbidimeter	4/day
	Filter Feed		
	TM1, JC, PMF, CMF, TM2 Effluents		
Pressure	Inlets: TM1, JC, PMF, CMF, TM2	Pressure Gauge	4 times/day
	Outlet: TM1, JC PMF, CMF, TM2		
Silt Density Index (SDI)	TM1 Effluent	Hand-held filter apparatus with 0.45-micron pore size filter disks, a graduated cylinder, and a stop watch	Once every 2 days and/or after a significant change in filter operations and/or filter influent
	JC Effluent		
	PMF Effluent		
	TM2 Effluent		
Flow Rate	CTP Effluent (at Outfall 006)	Flow meter	1/day
	TM1, JC, TM2 Effluents	Rotameters	4/day
	PMF Effluent and Recirculation		
	CMF Effluent and Recirculation		
Specific Gravity	Recirculated Sludge from CTP Thickener underflow	Gravimetric	1-3/day

All parameters are measured on grab samples or as instantaneous readings.

Table 6

Phase 2B Cadmium Data [mg/L]

Sample Date	CTP infl (S1) total	CTP effl (S2) total		CTP effl+solids (S3) total		TM1 effl (S4) total	JC effl (S5) total	PMF effl (S6) total	CMF effl (S7) total	TM2 effl (S8) total
		dissolved		dissolved						
Lime-Only Treatment WITHOUT solids spiking of CTP effluent										
08-Jul		0.39	0.29	W		0.19	0.24	0.27	0.30	
09-Jul		0.38	0.37			0.25	W 0.33	W 0.31	0.31	
10-Jul		0.32	W 0.36	W		0.23	W 0.24	W 0.19	W 0.19	W
avg		0.36	0.34			0.22	0.27	0.26	0.27	
Lime-Only Treatment WITH solids spiking of CTP effluent										
11-Jul	195	0.60	0.61		2.9	W 0.50	0.26	W 0.23	W 0.25	W 0.26
12-Jul		0.63	W 0.65	W	3.2	W 2.6	W 0.22	W 0.24	W 0.19	W 0.19
13-Jul		0.57	0.55		4.0	2.9	0.20	0.33	0.22	0.23
14-Jul		0.51	0.53		3.8	2.8	0.28	0.24	0.22	0.29
15-Jul										
16-Jul		0.56	0.53		3.8	2.5	0.33	0.20	W 0.16	W 0.19
17-Jul	216	1.2	W 1.1	W	4.5	W 3.2	0.39	0.38	0.55	W
18-Jul		1.7	1.8		5.6	4.2	0.85	0.79	1.0	
19-Jul		0.62	J* 0.80	J*	3.9	J* 2.8	WJ* 0.27	J* 0.24	J* 0.23	WJ*
20-Jul		1.6	W 0.53	W	4.8	W 2.7	0.17	W 0.17	W 0.14	W
21-Jul		2.2	0.66		7.9	5.2	0.18	0.17	0.18	
22-Jul										
23-Jul		0.51	W 0.41	W	8.3	5.0	1.2	W 0.28	W	
24-Jul	158	0.33	W 0.3	W	5.9	3.7	0.18	0.17	W	
25-Jul		0.39	0.38	W	4.7	W 3.1	0.14	0.30		
26-Jul		0.46	0.40		5.3	3.4	0.18	0.14		
27-Jul		0.32	0.32	W	4.8	W 2.9	0.11	0.19	W	
avg	190	0.74	a 0.59	a	4.9	3.2	0.33	0.27	0.31	0.23
Lime+Sulfide Treatment WITH solids spiking of CTP effluent										
28-Jul		0.42	0.35		6.3	5.0	0.16	W 0.26	W 0.13	0.25
29-Jul		0.36	W 0.35	W	5.0	W 3.2	W 0.07	W 0.05	W 0.02	W 0.09
30-Jul		0.34	W 0.28		4.7	W 3.3	W 0.14	W 0.08	W 0.08	W 0.04
31-Jul	159	0.38	W 0.30	W	6.2	3.3	W 0.19	W 0.07	W 0.02	W 0.02
01-Aug		0.22	W 0.19	W	6.3	3.3	W 0.04	W 0.03	W 0.02	UW 0.02
02-Aug		0.25	W 0.25		4.3	3.7	W 0.12	W 0.09	W	0.14
03-Aug		0.35	0.27		6.1	3.5	0.12	0.08		0.11
04-Aug		0.21	0.21		4.9	2.9	0.11	0.04	W	0.11
avg		0.32	0.28		5.5	3.5	0.12	0.09	0.05	0.08
Lime-Only Treatment WITH solids spiking of CTP effluent										
14-Aug		0.29	0.29		3.2	2.3	0.21	W		0.19
15-Aug	142	0.31	W 0.30	W	3.6	W 2.5	0.18	W		0.22
16-Aug		0.39	0.32		5.4	3.1	W 0.29			0.23
17-Aug		0.23	W 0.21		4.0	1.5	0.13			0.12
18-Aug		0.27	0.25		4.8	2.6	0.18			0.14
avg		0.30	0.27		4.2	2.4	0.20			0.18

U = not detected above given IDL B qualifiers (CRDL>value>IDL) are not shown because the CLP CRDLs are much greater than levels of interest to this project.

W = post-digestion spike is outside control limits (85-115%), while sample absorbance is <50% of spike absorbance J* = estimated value, per data validation

a Averages include data from July 8-27, since the full-scale trial treatment process was the same

U* = not detected above given value, per data validation

Table 7
Phase 2B Lead Data [mg/L]

Sample Date	CTP infl (S1) total	CTP effl (S2) total		CTP effl+solids (S3) total		TM1 effl (S4) total	JC effl (S5) total	PMF effl (S6) total	CMF effl (S7) total	TM2 effl (S8) total
		dissolved		dissolved						
Lime-Only Treatment WITHOUT solids spiking of CTP effluent										
08-Jul		0.68 W	0.49 UW			0.49 U	0.49 UW	2.0 W	4.0 W	
09-Jul		0.54 W	0.87 W			0.49 U	0.49 U	0.56 W	1.8	
10-Jul		0.65 W	0.49 W			0.49 UW	0.49 UW	5.2 W	1.4 W	
avg		0.62	0.62			0.49	0.49	2.6	2.4	
Lime-Only Treatment WITH solids spiking of CTP effluent										
11-Jul	569	0.58 W	0.49 UW	6.0 W	0.49 UW	0.49 UW	0.49 UW	1.9 W	0.85 W	
12-Jul		0.75 W	0.49 UW	8.3	0.61	0.49 UW	1.2 W	0.49 UW	0.49 UW	
13-Jul		3.6 W	0.50	9.6 W	0.49 U	0.49 U	0.54	1.1	0.91	
14-Jul		1.1	1.2	9.8	0.49 U	0.49 U	0.49 U	0.49 U	0.67 W	
15-Jul										
16-Jul		0.72 W	0.49 UW	10.5	0.49 U	0.49 U	0.49 U	0.49 U	0.60 W	
17-Jul	546	1.7	1.3	11.3	0.49 U	0.49 U	0.49 U	0.49 U		
18-Jul		1.4 W	0.49 UW	12.4 W	0.49 U	0.89 W	0.49 U	0.63		
19-Jul		1.2 W	0.55	11.6	0.49 UW	0.49 U	0.49 U	0.49 U		
20-Jul		1.8	0.49 U	15.2	0.65	0.61	0.49 U	0.97		
21-Jul		1.6	0.49 U	21.8	0.49 U	0.68	0.49 U	0.49 U		
22-Jul										
23-Jul		1.2	0.49 U	24.1	0.49 U	3.7	0.71			
24-Jul	635	0.49 UJ*	0.49 UW	12.2 J*	0.49 U	0.53	0.49 U			
25-Jul		0.77	0.49 U	10.9	0.49 U	0.49 U	0.58			
26-Jul		0.68 W	0.49 UW	13.7	0.49 U	0.49 UW	0.49 UW			
27-Jul		0.49 U	0.49 U	18.5	0.49 U	0.49 U	0.49 U			
avg	583	1.08 a	0.60 a	13.1	0.51	0.75	0.56	0.75	0.70	
Lime+Sulfide Treatment WITH solids spiking of CTP effluent										
28-Jul		0.87	0.49 U	15.3	0.90	0.53	0.58	1.6	6.3	
29-Jul		0.86 W	0.49 UW	17.6	0.49 UW	0.49 U	0.49 U	0.49 UW	0.49 UW	
30-Jul		0.88	0.49 U	17.0	0.49 U	0.49 U	0.49 U	0.49 U	0.49 U	
31-Jul	591	0.79	0.49 U	18.8	0.49 U	0.49 UW	0.49 U	0.63	0.55	
01-Aug		0.71	0.49 U	8.7	0.49 U	0.49 U	0.49 U	0.82	0.70	
02-Aug		0.85	0.49 U	15.7	0.49 UW	0.49 U	0.49 U			0.49 U
03-Aug		0.57 W	0.78 W	18.9	0.49 U	0.49 UW	0.49 U			0.49 U
04-Aug		0.68	0.49 U	13.3	0.49 UW	0.49 U	0.49 U			0.49 U
avg		0.78	0.53	15.7	0.54	0.50	0.50	0.81	1.71	0.49
Lime-Only Treatment WITH solids spiking of CTP effluent										
14-Aug		0.49 U	0.49 UW	8.7 W	0.49 UW	0.49 UW				0.49 UW
15-Aug	574	0.74 W	0.49 UW	14.5	0.49 UW	2.65 W				0.49 UW
16-Aug		0.49 UW	0.49 U	18.6	0.49 UW	0.49 UW				0.49 U
17-Aug		0.49 U	0.49 U	16.4	0.49 U	0.49 U				0.49 U
18-Aug		0.49 U	0.49 UW	16.7	0.49 U	0.49 U				0.49 U
avg		0.54	0.49	15.0	0.49	0.92				0.49

U = not detected above given IDL B qualifiers (CRDL>value>IDL) are not shown because the CLP CRDLs are much greater than levels of interest to this project.

W = post-digestion spike is outside control limits (85-115%), while sample absorbance is <50% of spike absorbance J* = estimated value, per data validation

a Averages include data from July 8-27, since the full-scale trial treatment process was the same

U* = not detected above given value, per data validation

Table 8
Phase 2B Zinc Data [mg/L]

Sample Date	CTP infl (S1) total	CTP effl (S2) total dissolved		CTP effl+solids (S3) total dissolved		TM1 effl (S4) total	JC effl (S5) total	PMF effl (S6) total	CMF effl (S7) total	TM2 effl (S8) total
Lime-Only Treatment WITHOUT solids spiking of CTP effluent										
08-Jul		82.8	31.5			13.3	12.7	22.0	19.8	
09-Jul		93.0	86.6			15.1	19.8	22.4	20.3	
10-Jul		104	98.8			17.5	21.1	24.4	35.8	
avg		93.3	72.3			15.3	17.9	22.9	25.3	
Lime-Only Treatment WITH solids spiking of CTP effluent										
11-Jul	113000	235	206	1910	133	20.1 U*	17.9 U*	15.9 U*	19.8 U*	
12-Jul		254	226	2340	1600	31.6	18.0 U*	16.4 U*	16.0 U*	
13-Jul		191	184	2200	1540	20.6	24.7	21.0	24.0	
14-Jul		143	127	2160	1560	20.7	16.7	16.2	16.5	
15-Jul										
16-Jul		218	179	2350	1350	41.3	24.7	18.0	20.3	
17-Jul	110000	400	290	2570	1660	24.9	25.5	27.7		
18-Jul		324	260	2740	1430	34.8	35.7	24.6		
19-Jul		232	170	2460	1440	17.5	16.3	16.6		
20-Jul		324	257	3490	1600	19.8	13.3	10.8		
21-Jul		314	227	4790	2590	42.2	39.2	30.3		
22-Jul										
23-Jul		178	138	5240	2530	750	116			
24-Jul	112000	133	106	4160	2160	55.0	44.9			
25-Jul		173	128	3450	1780	33.3	152			
26-Jul		158	135	2790	1560	14.1	12.6			
27-Jul		134	119	3300	1680	15.6	76.1			
avg	111667	199 a	160 a	3063	1641	28.0 b	37.0 b	19.8	19.3	
Lime+Sulfide Treatment WITH solids spiking of CTP effluent										
28-Jul		178	161	3390	2870	21.9	102	22.0	41.2	
29-Jul		223	191	3860	1630	16.7	22.7	21.1	20.9	
30-Jul		186	159	3290	1760	42.7	15.4	17.2	17.6	
31-Jul	100000	220	197	5220	2110	23.9	35.9	16.4	19.6	
01-Aug		166	150	4920	1990	23.4	27.1	28.3	23.1	
02-Aug		138	130	3890	2100	23.7	20.8			47.9
03-Aug		137	133	3820	2070	17.1	8.5			14.5
04-Aug		108	97.2	2590	1640	12.8	9.9			29.7
avg		170	152	3873	2021	22.8	30.3	21.0	24.5	30.7
Lime-Only Treatment WITH solids spiking of CTP effluent										
14-Aug		66.9	56.8	2200	1310	36.9				24.5
15-Aug	93000	76.5	62.9	2990	1680	20.6				43.0
16-Aug		93.6	85.7	3540	1660	20.1				61.4
17-Aug		67.4	61.5	2770	888	16.1				18.1
18-Aug		61.4	60.8	3210	1680	18.2				16.0
avg		73.2	65.5	2942	1444	22.4				32.6

U = not detected above given IDL B qualifiers (CRDL>value<IDL) are not shown because the CLP CRDLs are greater than levels of interest to this project.

a Averages include data from July 8-27, since the full-scale trial treatment process was the same

J* = estimated value, per data validation

b Average excludes 23-July data

U* = not detected above given value, per data validation

Table 9

Phase 2B TSS, Lime Demand/Solids Formed, and pH Data

Sample Date	TSS [mg/L]								Lime demand [lbs/kgal]	Solids formed [lbs/kgal]	pH [pH units]	
	CTP effl (S2)	CTP effl+solids (S3)	TM1 effl (S4)	JC effl (S5)	PMF effl (S6)	CMF effl (S7)	TM2 effl (S8)	CTP thickener			CTP outfall	
								CTP infl	CTP infl			
Lime-Only Treatment WITHOUT solids spiking of CTP effluent												
08-Jul	5		3	2 U							9.2	9.2
09-Jul	3		4	2 U							9.1	9.1
10-Jul	2 U		2 U	6							9.0	8.4
avg	3.3		3.0	3.3							9.1	8.9
Lime-Only Treatment WITH solids spiking of CTP effluent												
11-Jul	2	16	4	2				6.68	7.21		9.1	9.1
12-Jul	3	12	2	3							9.4	9.2
13-Jul	2	11	2	3							9.3	9.2
14-Jul	3	10	2	4							9.4	9.2
15-Jul											9.4	9.2
16-Jul	4	16	5	6							9.1	9.2
17-Jul	3	14	2 U	2				6.68	7.44		9.2	9.2
18-Jul	5	13	2 U	2							8.2	8.8
19-Jul	2 U	14	3	5	4						8.6	8.6
20-Jul	6	18	2 U	2 U	2						9.2	8.9
21-Jul	4	28	4	7	5						9.3	9.1
22-Jul											9.4	9.2
23-Jul	3	36	5	2 U							8.9	
24-Jul	2 U	15	9	2 U				6.34	7.00		9.1	9.1
25-Jul	6	19	6	2 U							9.1	8.9
26-Jul	2 U	18	2	2 U							9.2	9.1
27-Jul	3	22	8	6							9.5	9.1
avg	3.3 *	17.5	3.9	3.3	3.7			6.57	7.22		9.1	9.1
Lime+Sulfide Treatment WITH solids spiking of CTP effluent												
28-Jul	7	26	4	4	3	2					9.5	9.1
29-Jul	5	24	6	6	3	4					9.4	9.2
30-Jul	6	24	6	7	6	4					9.3	9.2
31-Jul	5	35	8	7	8	6		6.68	7.77		9.3	9.1
01-Aug	6	30	4	6	2	5					8.9	8.7
02-Aug	2	24	7	4			5				8.9	8.8
03-Aug	6	22	4	2			6				9.1	9.1
04-Aug	7	17	2	4			4				9.2	9.1
avg	5.5	25.3	5.1	5.0	4.4	4.2	5.0				9.2	9.0
Lime-Only Treatment WITH solids spiking of CTP effluent												
14-Aug	4	15	7				5				9.3	9.0
15-Aug	2	20	2 U				2 U	6.34	6.62		9.3	9.1
16-Aug	2 U	20	2 U				2 U				9.3	9.2
17-Aug	2 U	21	2 U				3				9.3	9.3
18-Aug	2 U	22	2 U				2				9.3	9.3
avg	2.4	19.6	3.0				2.8				9.3	9.2

U = not detected at given reporting limit

* Average includes data from July 8-27, since the full-scale trial treatment process was the same

Table 10
Phase 2B TAL Metals Data

Analyte	Lime-only Treatment, 16-July				Lime-only Treatment, 25-July				Lime-only ^a , 15-Aug	
	TM1 effl S4	JC effl S5	PMF effl S6	PMF effl S7	CTP effl S2	CTP effl+ solids S3	TM1 effl S4	JC effl S5	TM1 effl S4	TM2 effl S8
Aluminum	206	145	138	141	29.4 UN	121 N	29.4 UN	29.4 UN	73.5	50.1
Antimony	5.6 U	5.6 U	5.6 U	5.6 U	5.6 U	5.6 U	5.6 U	5.6 U	5.6 U	5.6 U
Arsenic	5.6 U	5.6 U	5.6 U	5.6 U	5.6 U	5.6 U	5.6 U	5.6 U	5.6 U	5.6 U
Barium	7.1	4.4	5.5	4.3	7.9	5.7	4.6	4.1	3.5	2.5
Beryllium	0.58 U	0.58 U	0.58 U	0.58 U	0.58 U	0.58 U	0.58 U	0.58 U	1.4	1.2
Cadmium	0.33 N	0.20 NW	0.16 NW	0.19 NW	0.39	4.7 W	0.14	0.30	0.18 W	0.22
Calcium	675000	655000	686000	662000	617000	653000	609000	630000	590000	569000
Chromium	0.32 U	0.32 U	0.32 U	0.32 U	0.32 U	0.32 U	0.32 U	0.32 U	0.32 U	0.32 U
Cobalt	0.46 U	0.46 U	0.46 U	0.46 U	0.46 U	2.0	0.46 U	0.46 U	0.46 U	0.46 U
Copper	3.7 U	3.7 U	3.7 U	3.7 U	3.7 U	3.7 U	3.7 U	30.7	93.2	3.7
Iron	73.0	42.0	55.3	20.2	124	2710	8.2 U	97.8	22.2	37.3
Lead	0.49 U	0.49 U	0.49 U	0.60 W	0.77 *	10.9 *	0.49 U*	0.58 *	2.6 W	0.49 UW
Magnesium	135000	133000	134000	132000	140000	140000	139000	139000	158000	157000
Manganese	0.26 U	0.26 U	0.26 U	0.26 U	156 *	4170 *	4.8 *	133 *	6.6	21.0
Mercury	0.02	0.02	0.02	0.02	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.04
Nickel	2.6 U	2.6 U	2.6 U	2.6 U	2.6 U	2.6 U	2.6 U	2.6 U	2.6 U	2.6 U
Potassium	14000 E	14100 E	14100	14800 E	13600 E	13900 E	14000 E	14800 E	14000	14800
Selenium	9.6 U	9.6 U	9.6 U	9.6 U	9.6 U	9.7	9.6 U	9.6 U	9.6 U	9.6 U
Silver	2.6 U	2.6 U	2.6 U	2.6 U	2.6 U	2.6 U	2.6 U	2.6 U	2.6 U	2.6 U
Sodium	2780	3150	2850	2760	2910	2900	3300	2540	3020	2880
Thallium	12.9	6.8 U	6.8 U	6.8 U	9.8	14.4	6.8 U	6.8 U	6.8 U	6.8 U
Vanadium	0.40 U	0.40 U	0.40 U	0.40 U	0.40 U	0.40 U	0.40 U	0.40 U	0.40 U	0.40 U
Zinc	41.3	24.7	18.0	20.3	173	3450	33.3	152	20.6	43.0

All data are total metals, units = µg/L

^a Follow-up Lime-only treatment

U = not detected above given IDL

B qualifiers (CRDL>value>IDL) are not shown because the CLP CRDLs are much greater than levels of interest to this project.

E = reported value is an estimate because an interference was present

N = spike sample recovery outside control limits (75-125%)

* = duplicate analysis not within control limits

Figure 1
Test Conditions and Operating Schedule for (Initial) Lime-only Treatment

Filter	July 2000																													
	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27										
General	no sludge spiking										w/sludge spiking										higher sludge spiking									
TM1	flux=5														flux=4															
	b														2		b		2		2		2		2					
TM2	[Offline]																													
JC	flux=5														flux=4															
	b														2		b		2		2		2		2					
PMF	a				b				b				d																	
CMF	a				b				c																					

Notes:

 = online  = offline

flux units = gpm/ft²

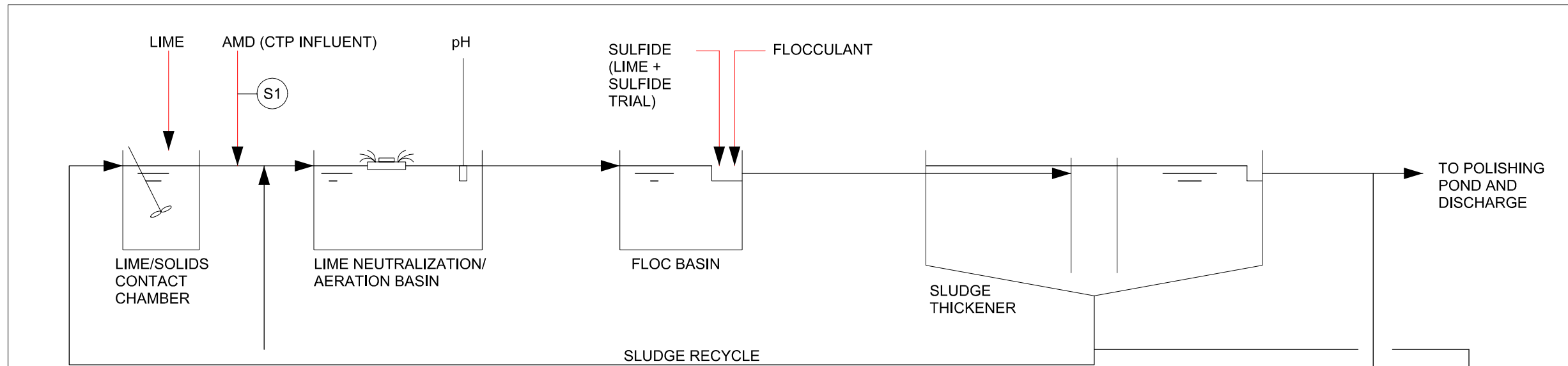
a - down for cleaning (high pressure loss)

b - CTP down for 24 hours to allow "lined pond" (AMD storage) to fill

c - CMF shut down because of low effluent pressure

d - PMF shut down because of leak and need for cleaning

2 - filter backwashing frequency = twice per day; otherwise generally once per day



FULL-SCALE CTP

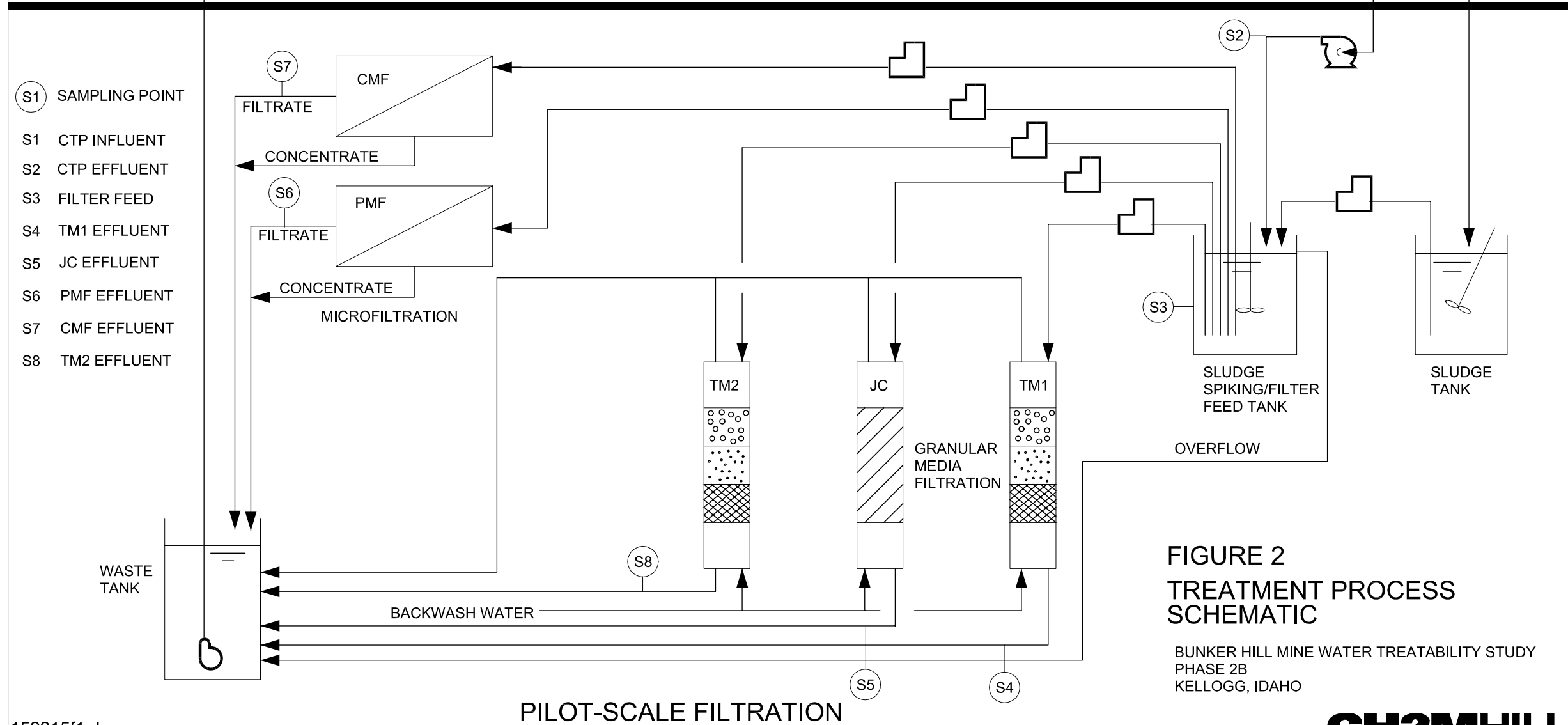


FIGURE 2
TREATMENT PROCESS
SCHEMATIC

BUNKER HILL MINE WATER TREATABILITY STUDY
PHASE 2B
KELLOGG, IDAHO

Figure 3
Filter Performance - Cadmium Removal

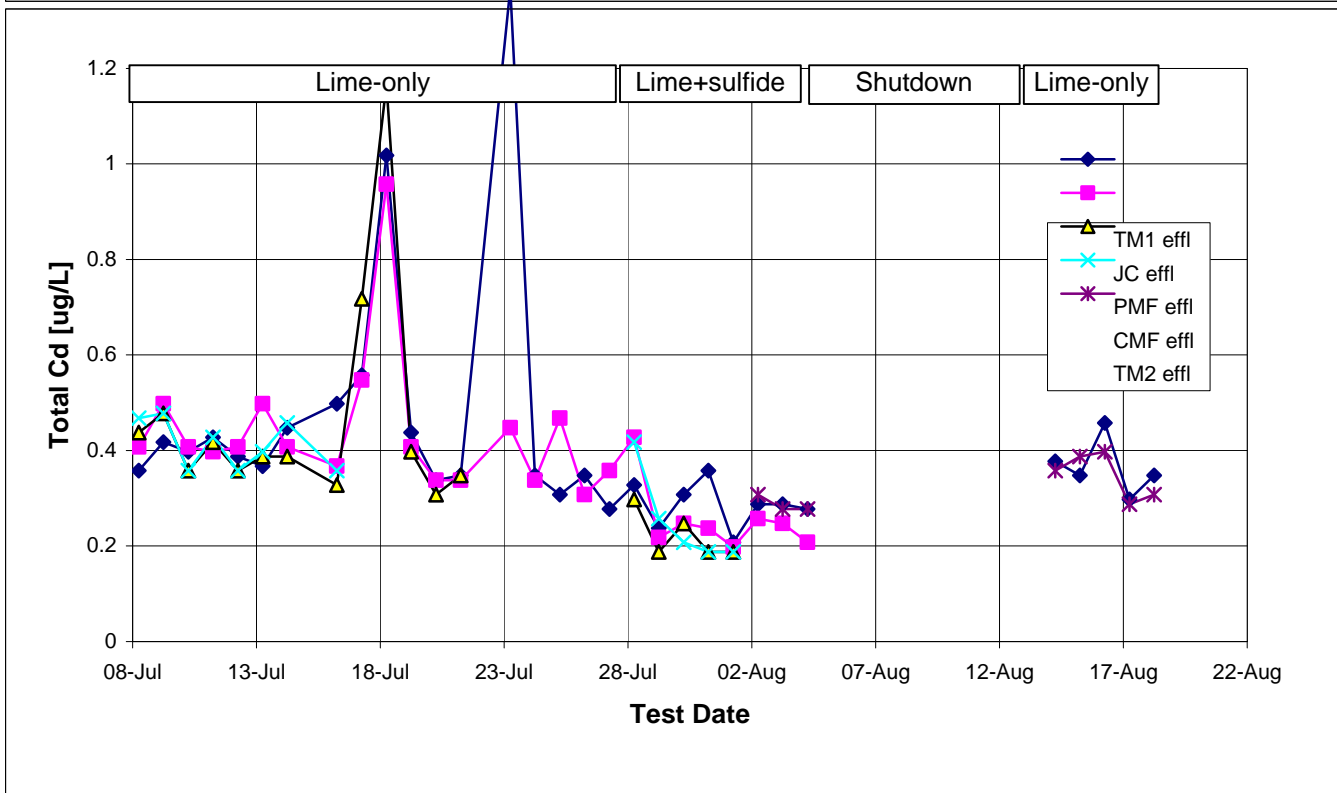
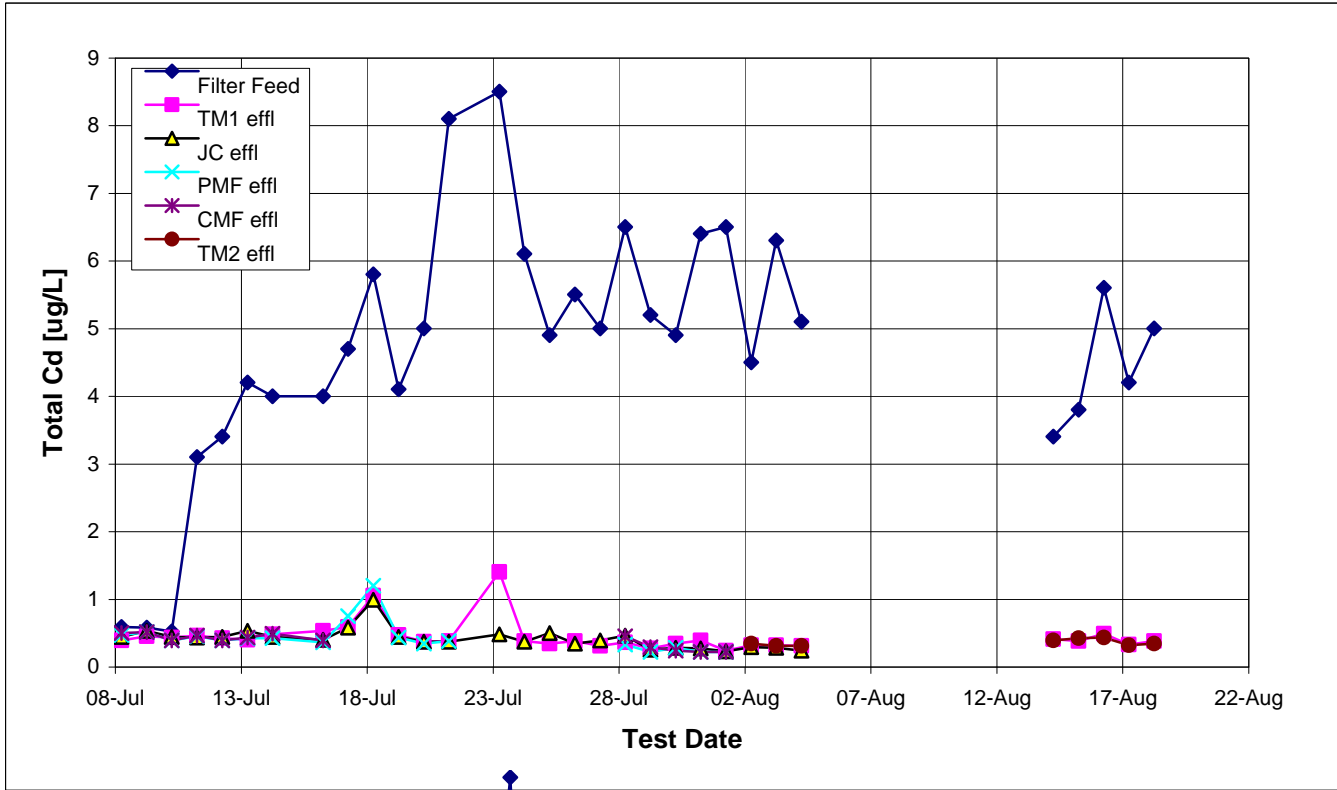


Figure 4
Filter Performance - Lead Removal

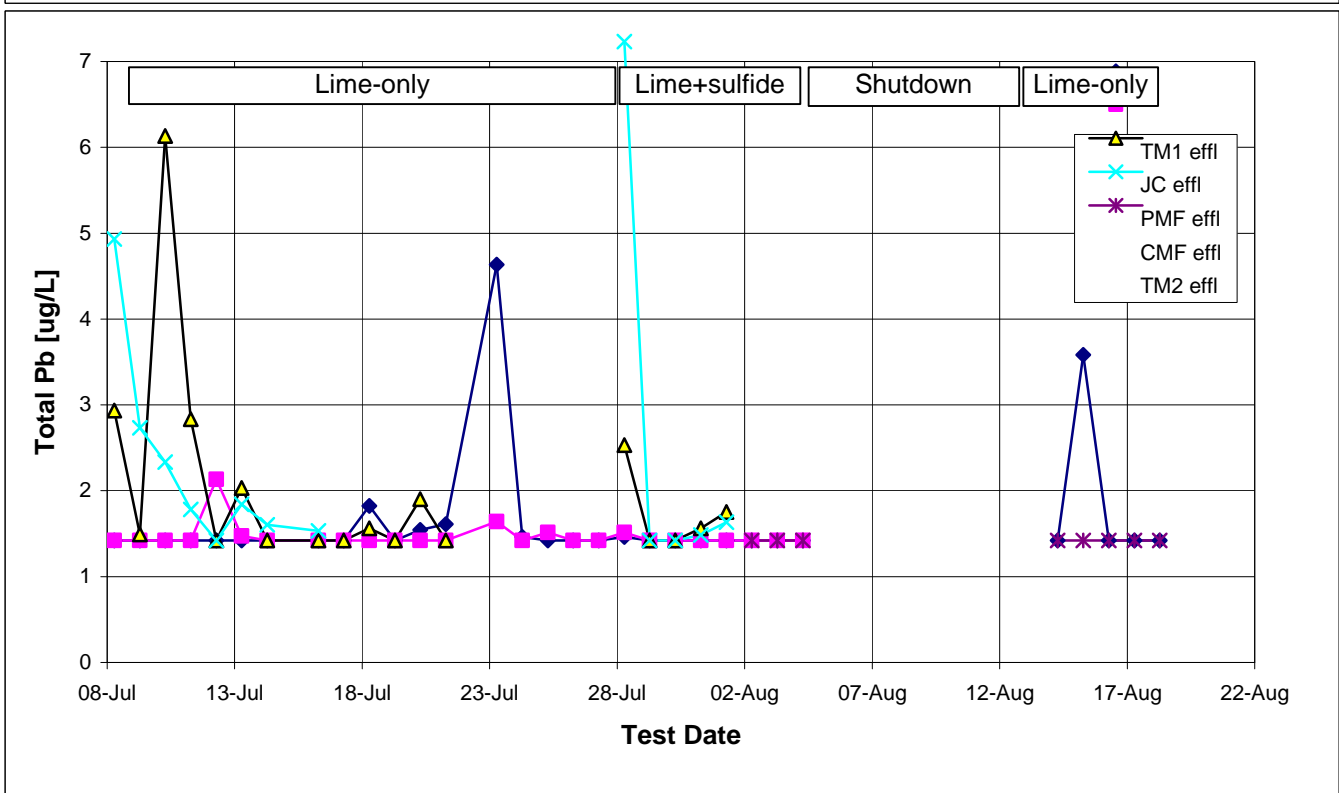
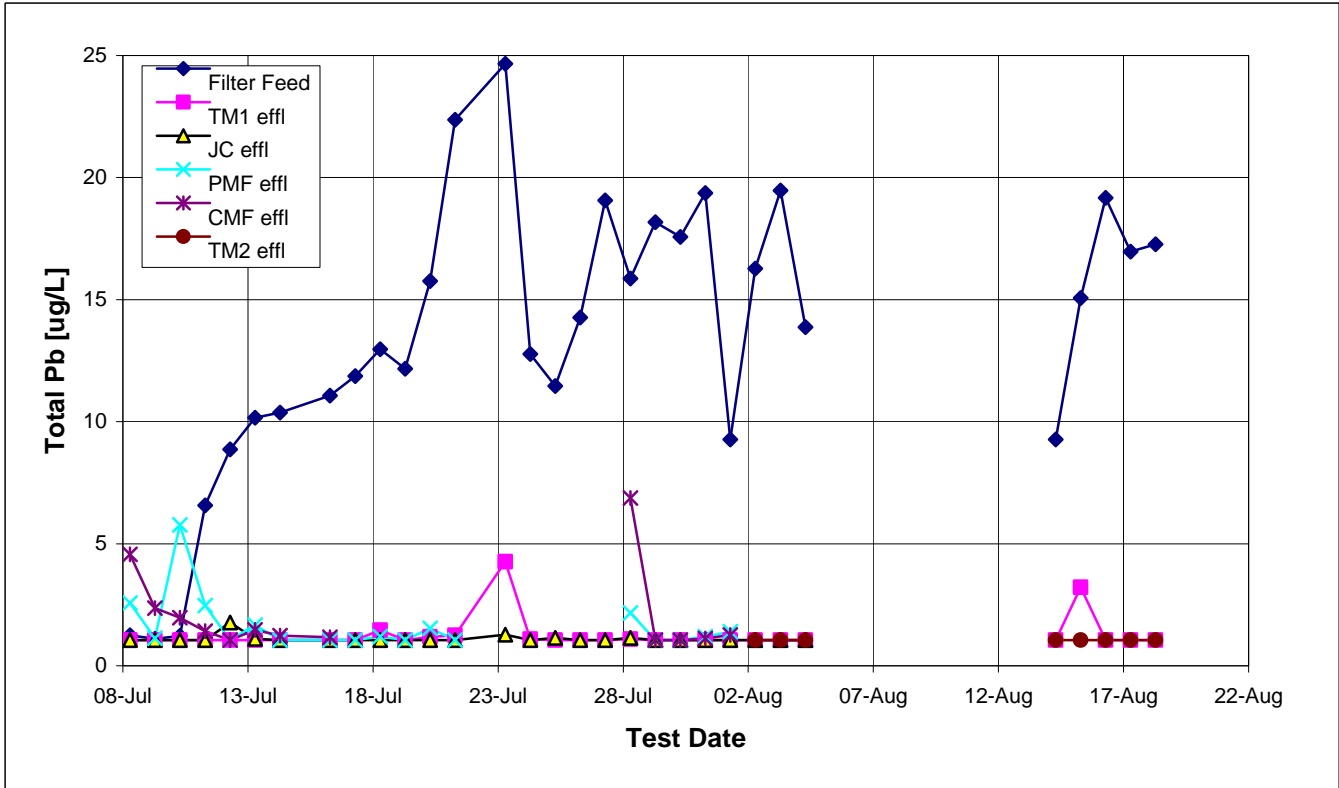


Figure 5
Filter Performance - Zinc Removal

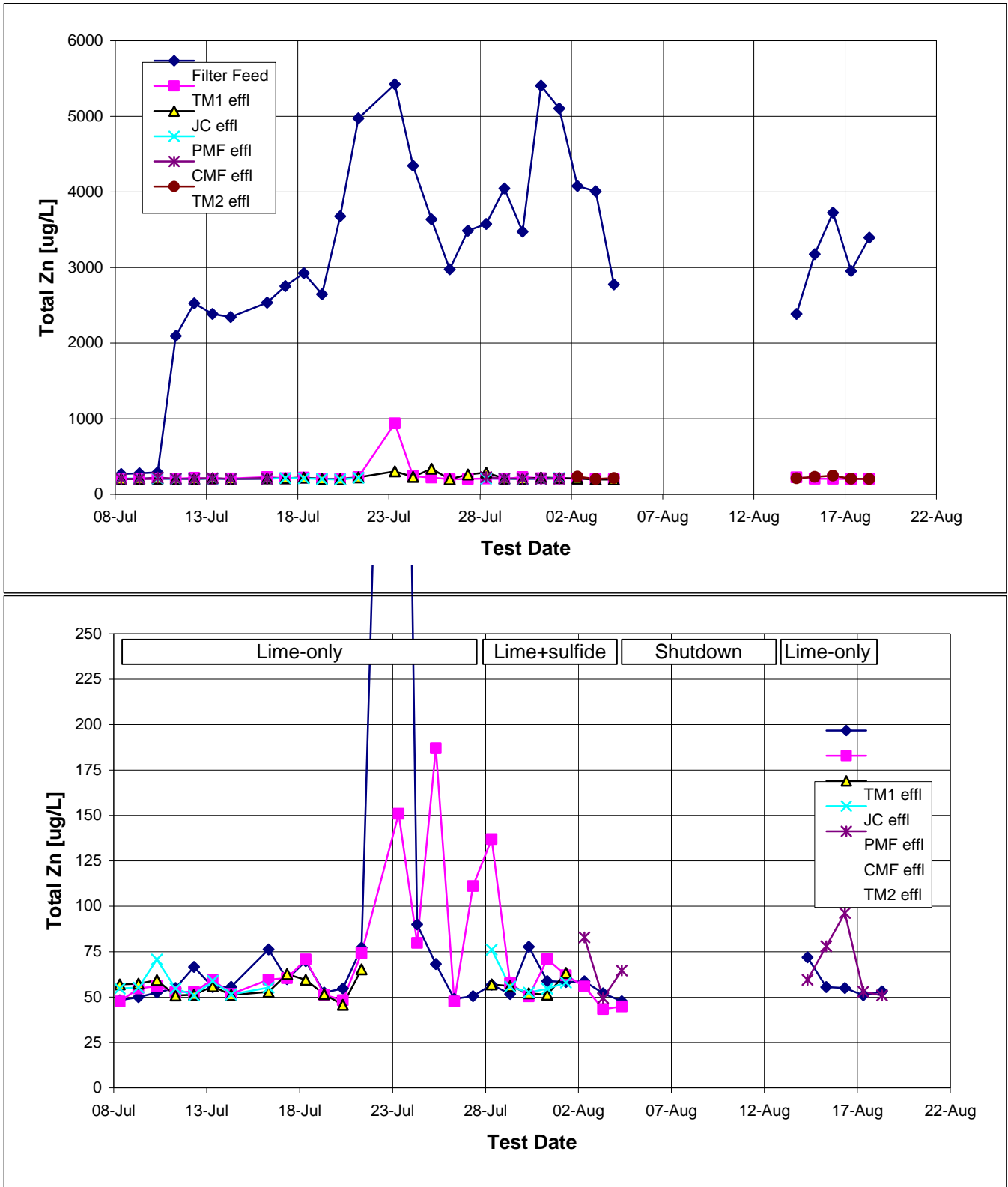


Figure 6. Filter Performance - TSS Removal

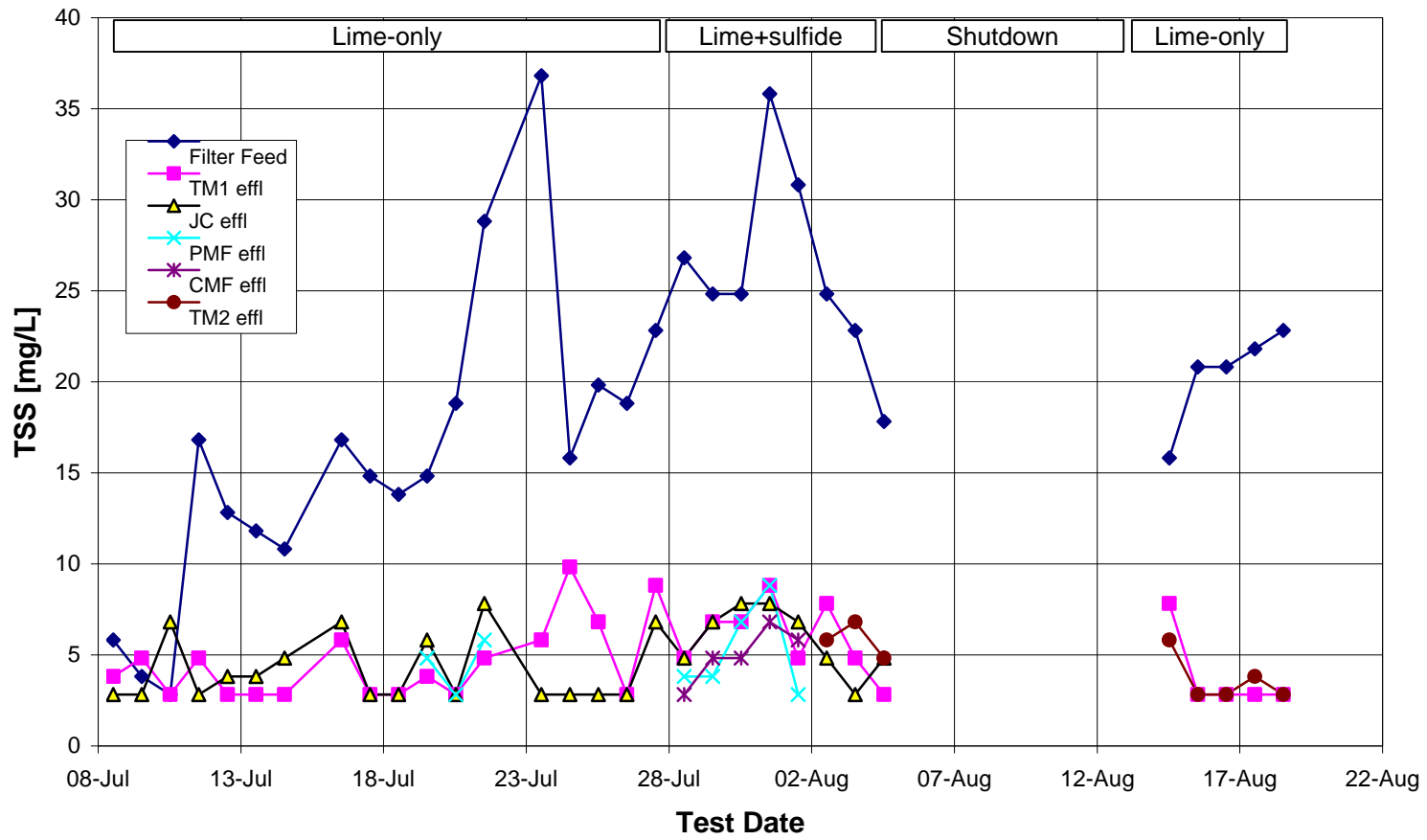


Figure 7
Test Conditions and Operating Schedule for Lime+sulfide Treatment

Filter	July 2000				August 2000			
	28	29	30	31	1	2	3	4
General	Elevated sludge spiking →							
TM1	<div style="background-color: #000080; height: 15px; width: 100%;"></div> flux=5 w/prefilter → flux=4 no prefilter → flux=5 flocculent → flux=4 flocculent →							
TM2					<div style="background-color: #000080; height: 15px; width: 100%;"></div> flux=4 flocculent → flux=5 flocculent →			
JC	<div style="background-color: #000080; height: 15px; width: 100%;"></div> flux=5 w/prefilter → flux=4 no prefilter → flux=5 flocculent →							
PMF								
CMF								

Notes:

= online = offline

flux units = gpm/ft²

TM1 and TM2 filter backwashing frequency = once per day

Figure 8
Test Conditions and Operating Schedule for Follow-up Lime-only Treatment

Filter	August 2000					
	14	15	16	17	18	19
General	Elevated sludge spiking →					
TM1						
	flux=4	→				a
	flocculent	→			2	2
TM2						
	flux=4	→				a
		→			2	2
JC						
PMF						
CMF						

Notes:

= online

= offline

flux units = gpm/ft²

a - shut down after sample recovery at 08:00

2 - filter backwashing frequency = twice per day; otherwise once per day

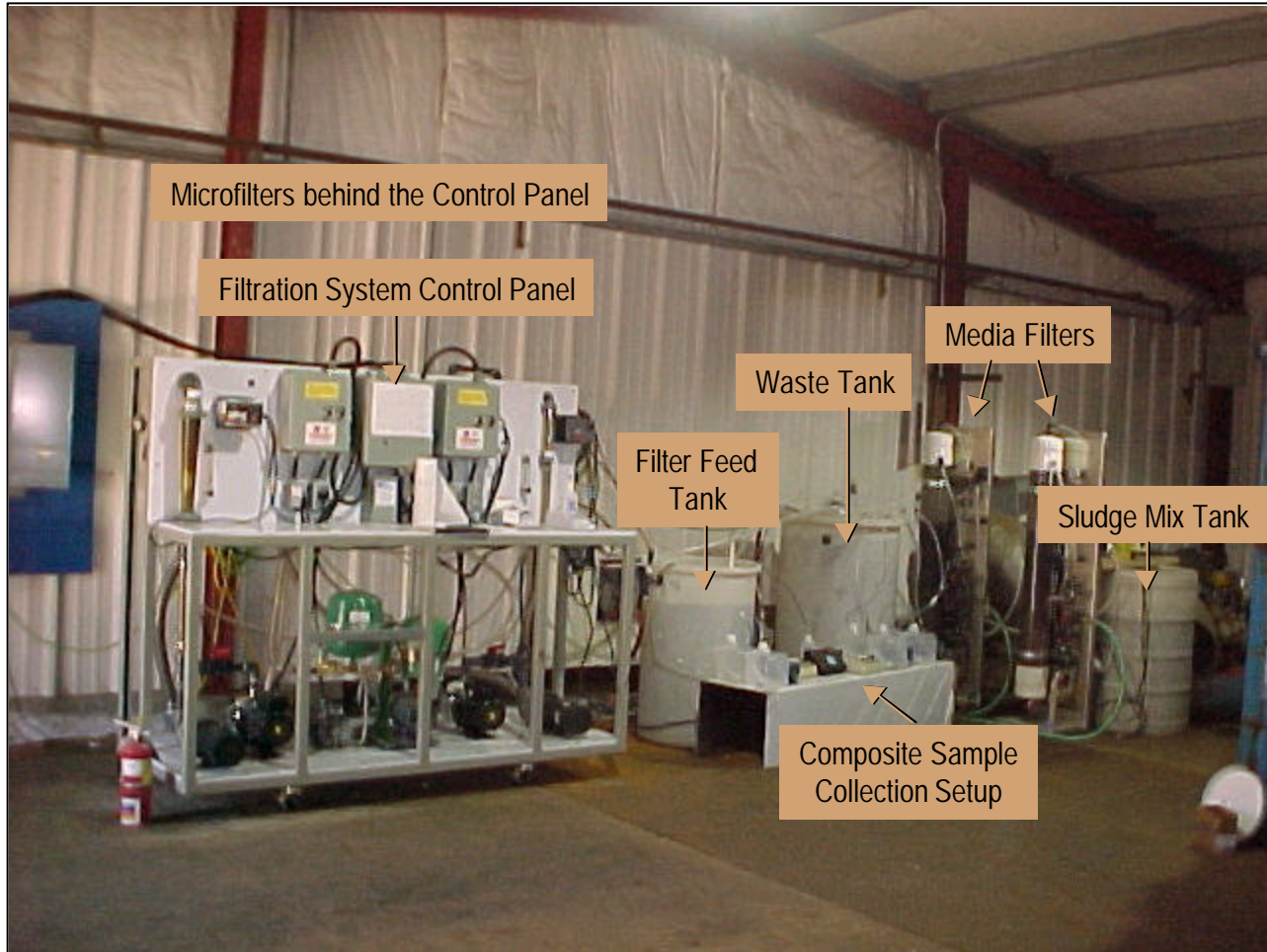


Photo 1
Filtration Pilot Unit Setup

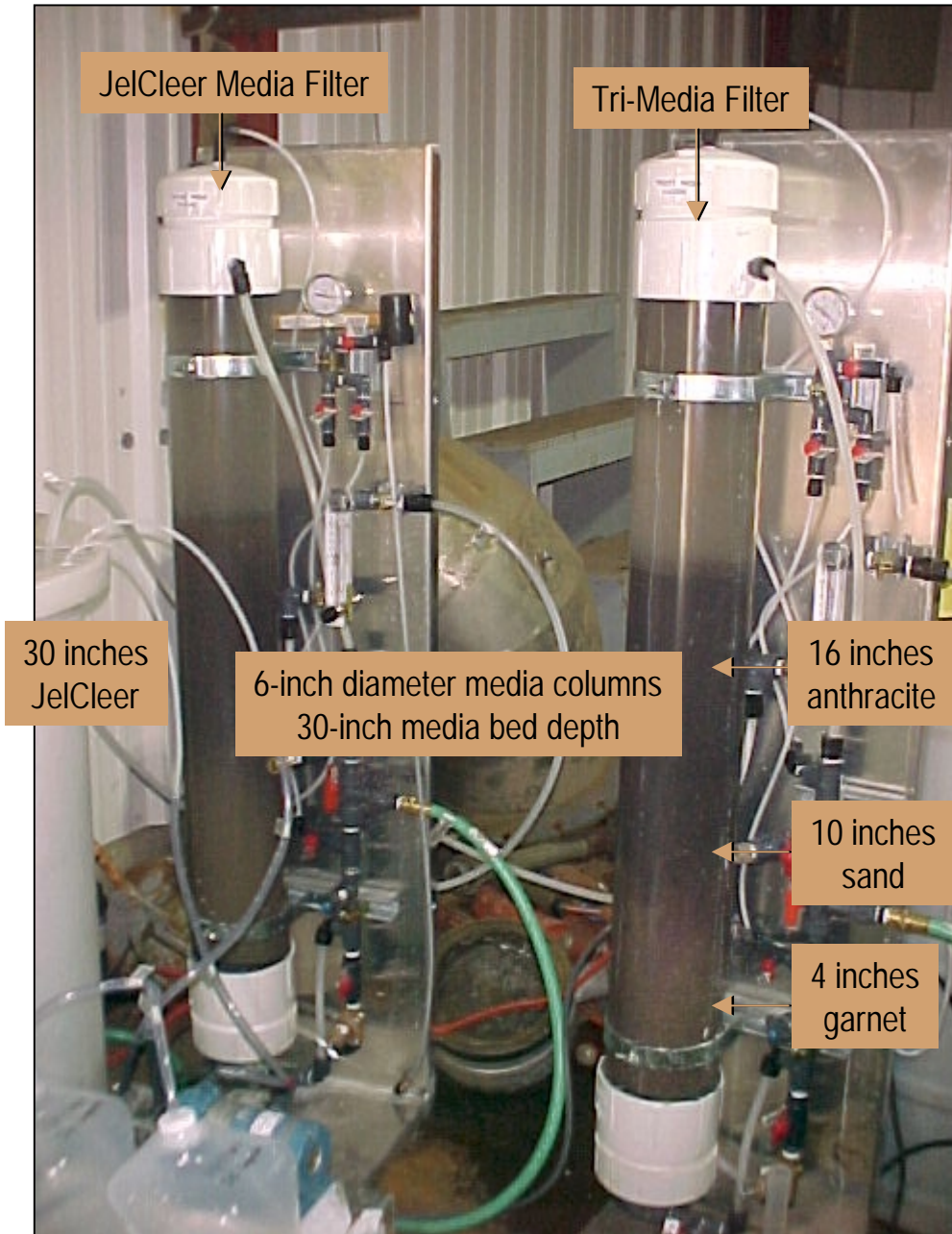


Photo 2
Media Filtration Units

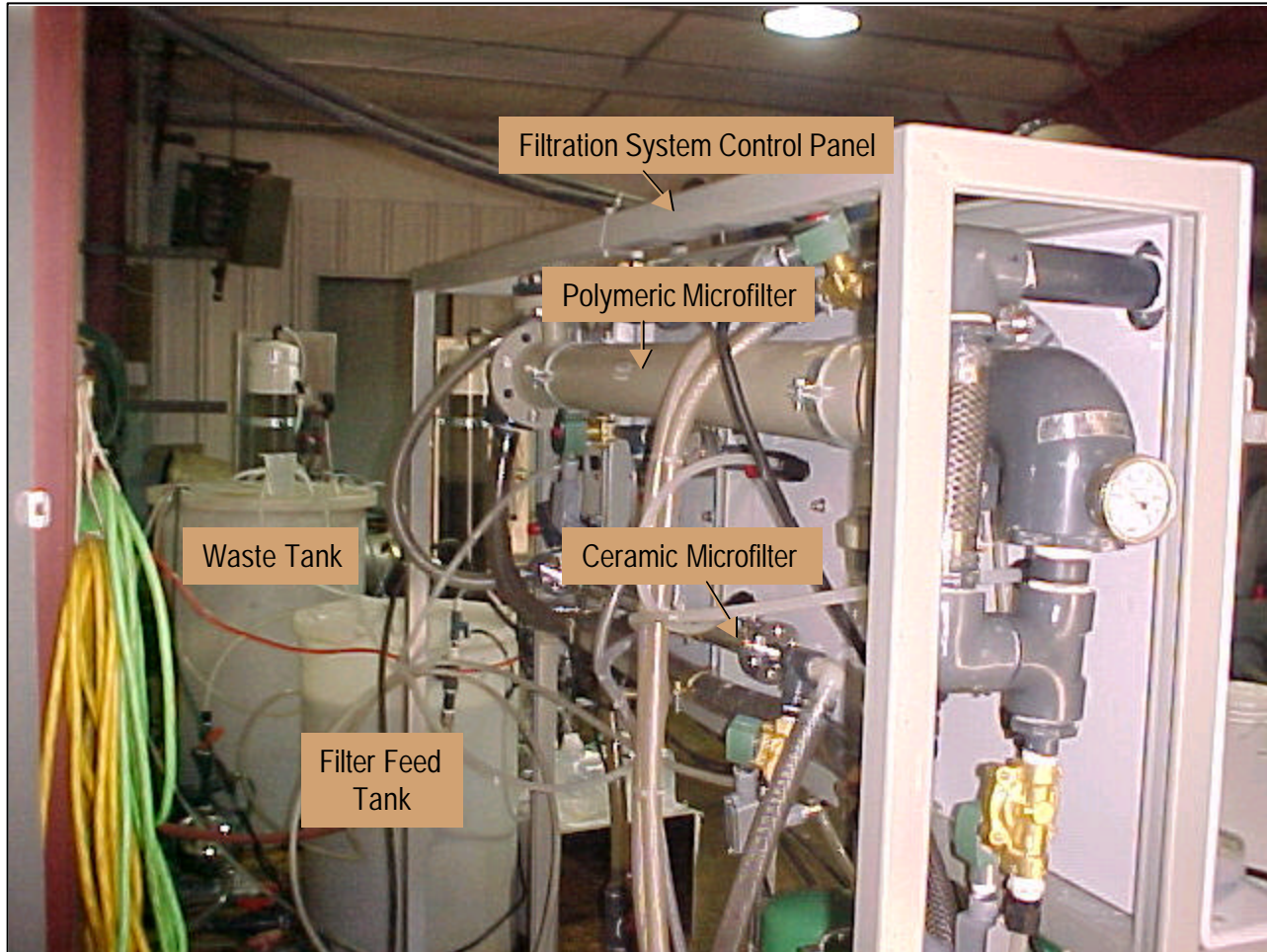


Photo 3
Microfiltration Units

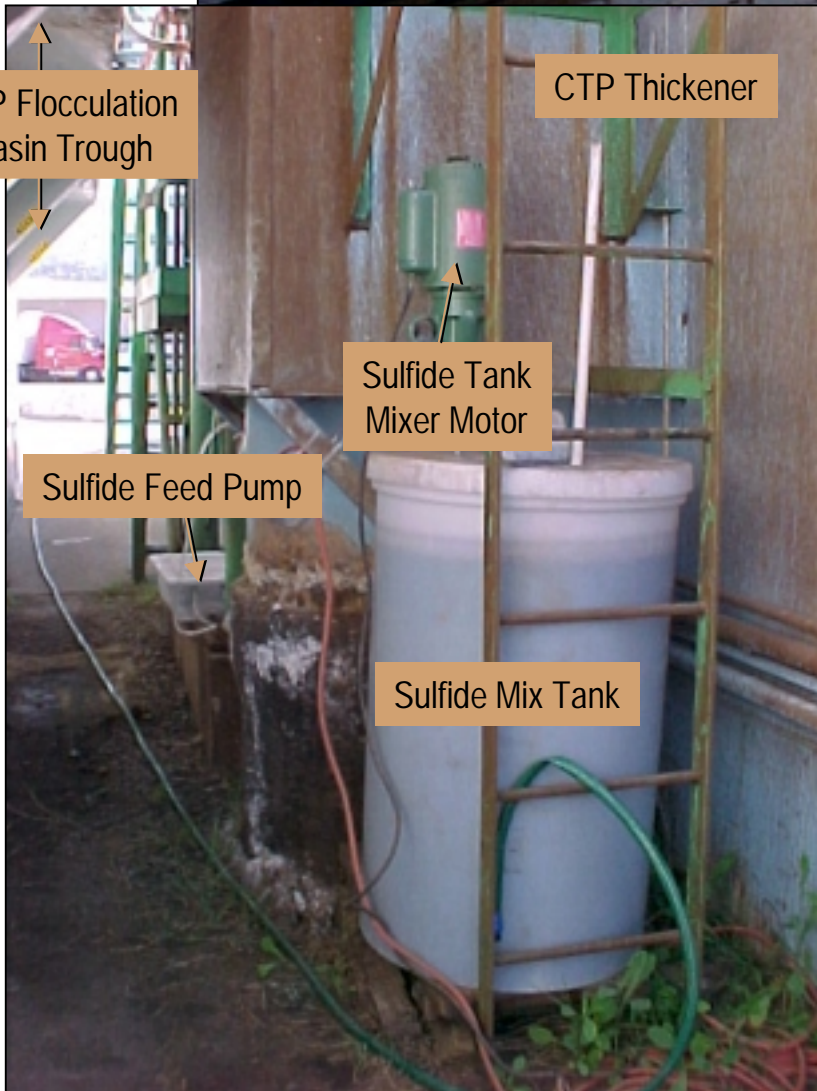
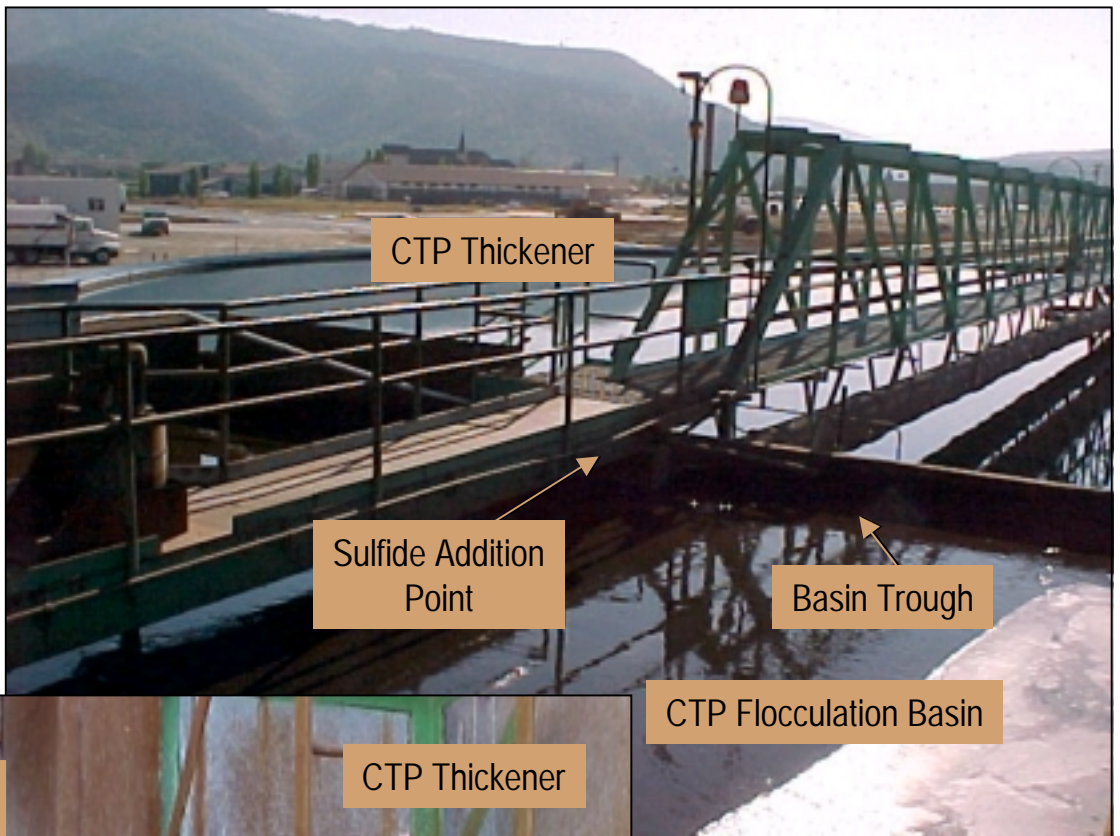


Photo 4
Sulfide Addition System