ROTATING CYLINDER TREATMENT SYSTEM DEMONSTRATION[1]

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Abstract. In August 2008, a rotating cylinder treatment system (RCTS^{TM}) demonstration was conducted near Gladstone, CO. The RCTS^{TM} is a novel technology developed to replace the aeration/oxidation and mixing components of a conventional lime precipitation treatment system for mining influenced water (MIW). The RCTS^{TM} realizes several operational benefits, including enhanced lime utilization by the treatment system, reduced maintenance requirements, and reduced power consumption by the aeration/mixing components of the treatment process.

Gladstone is located in the upper Animas River watershed, near Silverton, CO, at an elevation of about 10,500 ft. Approximately 1,500 abandoned mine sites exist in the region. Cement Creek, a tributary to the Animas River, is characterized by elevated metals concentrations and has a typical pH of 3.3. Aluminum, cadmium, copper, iron, manganese, and zinc are the primary mining-related contaminants of concern for Cement Creek. The American Tunnel drainage is a significant source of MIW entering Cement Creek, characterized as a reduced water with elevated concentrations of aluminum, cadmium, copper, iron, manganese, and zinc, and acidic pH.

During the two-week demonstration, the RCTS^{TM} treated surface water from Cement Creek and MIW discharged from the American Tunnel. The RCTS^{TM} was operated at flow rates ranging from 30 to 400 gallons per minute during this demonstration. Monitoring activities included logging field parameters including lime consumption, pH, temperature, dissolved oxygen, and oxidation-reduction potential, and collection of 50 samples for laboratory analysis.

This paper presents the results of the RCTS^{TM} demonstration, with an emphasis on evaluating RCTS^{TM} effluent water quality, and comparing the RCTS^{TM} lime consumption to conventional MIW treatment systems.

Additional Keywords: ARD, MIW, water treatment, rotating cylinder treatment system, RCTS^{TM}, heavy metals remediation, Green Remediation, lime precipitation, lime neutralization, economics

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[1] Paper was presented at the 2009 National Meeting of the American Society of Mining and Reclamation, Billings, MT, ***Revitalizing the Environment: Proven Solutions and Innovative Approaches*** May 30 – June 5, 2009. R.I. Barnhisel (Ed.) Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

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Proceedings America Society of Mining and Reclamation, 2009 pp 1323-1346
DOI: 10.21000/JASMR09011323
http://dx.doi.org/10.21000/JASMR09011323

Background

In August 2008, a mobile Rotating Cylinder Treatment System^{TM} (RCTS^{TM}) unit was mobilized to Gladstone, Colorado for a demonstration project planned by the US EPA ETSC Office of Research and Development, US EPA Region 8, Bureau of Land Management San Juan Public Lands Center, Ionic Water technologies Inc (IWT), and Golder Associates Inc (Golder). The demonstration was planned to include six days of RCTS^{TM} MIW treatment using two distinctly different MIW chemistries. Gladstone was selected as a desirable project site due to the regional history of mining related activities, the presence of MIW sources near Gladstone, the Site's elevation (10,500 ft) and a harsh mountain climate. Gladstone, Colorado is the site of an historic mining town that developed in the 1880's with the advent of mining in the surrounding area (Fig. 1).

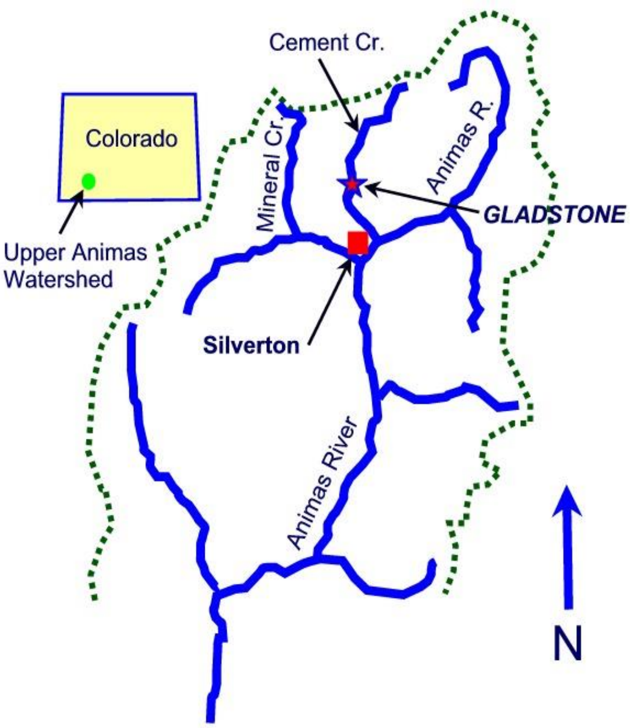

Figure 1: RCTS^{TM} Demonstration Site Location

Gladstone has historically been the central location, and railroad terminus for the milling and shipping of mine ores from this three square mile (2.6 square kilometer) valley. The American Tunnel was driven in the early 1900's, to develop lower levels of the Gold King mine. The tunnel drained up to 1,600 gallons per minute (gpm) from the Sunnyside Mine and functioned as an ore haulage adit until the mine's closure in 1991. As part of reclamation activities, three bulkheads were installed in the American Tunnel in 1996, 2001, and 2002 (START WTER) to stem the MIW discharge. Four settling ponds associated with the Sunnyside Mine's water treatment plant were removed in 2005, and the existing lime addition water treatment plant was decommissioned. Remnants of the American Tunnel water treatment plant were left on site for future treatment of MIW discharges. The Gold King Mine and water treatment plants are currently inactive. The American Tunnel portal is on public lands managed by the Bureau of Land Management. The tunnel continues to discharge about 100 gpm of MIW into Cement Creek.

Cement Creek is a state listed 303(d) stream, which flows south from Ross Basin, through Gladstone, and into the Animas River. Cement Creek receives MIW from numerous sources, including American Tunnel discharge. Below the American Tunnel, Cement Creek water quality is similar to typical acidic MIW water quality, containing a pH of 3.3 and elevated concentrations of Cd, Cu, Fe, Mn, and Zn. Cement Creek is unable to support aquatic life and only ambient water quality standards apply. Cement Creek is a major contributor of metals and acidity to the Animas River, which has "goal-based" Cold Water Aquatic Life I standards. Cement Creek is the primary remaining target for metals and acidity reduction necessary to bring the Animas River into Clean Water Act compliance.

Several inactive mine sites located in the Cement Creek watershed, including the American Tunnel, Gold King, Mogul, Grand Mogul, and Red and Bonita Mines, are ranked as high priority, low volume/high metal concentration acid mine drainages that are being considered for treatment in a common facility. The most likely candidate for this facility is the existing but currently idle lime treatment plant located in Gladstone. Resuming water treatment activities at the inactive lime treatment plant would likely require extensive renovations or replacement of the existing treatment system infrastructure.

The RCTS^{TM} demonstration was conducted to evaluate the performance of the technology when treating MIW in a remote high altitude setting. Gladstone, Colorado was selected as the location of this study due to its geographical characteristics, history of MIW sources, and an expressed interest in establishing a water treatment facility to treat MIW near Gladstone. Cement Creek (CC) and the American Tunnel discharge (AT) MIW sources were selected for use during the RCTS^{TM} demonstration due to their location and distinctly different MIW characteristics. The following sections outline the methodology used to monitor demonstration activities.

RCTS^{TM} Background

Typical active treatment systems designed for MIW streams reduce metals concentrations by raising the pH and oxidizing the MIW. At low pH, dissolved Fe and Mn typically exist primarily in reduced forms. These constituents can be precipitated from the dissolved phase by increasing the pH of the MIW (Wilmouth 1977). Oxidizing the MIW facilitates precipitation of Fe and Mn at a lower pH than is required to precipitate the reduced form of the chemicals (Stumm and Morgan 1981), and increases the kinetics of the precipitation reactions (Singer and Stumm 1969). Conventional MIW treatment systems use addition of CaO (lime) and mechanical aeration to accomplish pH adjustment and oxidation.

The RCTS^{TM} technology manufactured by IWT reportedly accomplishes chemical precipitation of metals from MIW sources while using less chemicals and energy than conventional treatment systems. The RCTS^{TM} includes a lime makedown tank, reaction tank, and a rotating perforated cylinder. Influent MIW enters the reaction tank, where it is mixed with metered volumes of lime slurry. The process water exits the reaction tank and enters the rotating cylinder via gravity flow. Inside the rotating cylinder unit, MIW flows parallel to the cylinder's axis of rotation, creating a shallow pool of water in the base of the unit. Two 0.5 horsepower motors spin the perforated cylinder through the shallow pool of water. The rotating cylinder aggressively mixes the process water, performs particle shearing of the lime particles added in the lime-dosing tank, and forces thin films of water up into the air during the mixing process, aerating the process water. RCTS effluent exits through a pipe located near the base of the unit under gravity flow conditions.

The effluent from the rotating cylinder is typically treated with a settling pond, clarifier, or other means of solid-liquid separation before final discharge (Tsukamoto 2006). The efficiency of the RCTS^{TM} is attributed primarily to the use of thin-film aeration. Rather than injecting air into MIW, the RCTS^{TM} introduces MIW to air in a thin film clinging to the rotating perforated cylinder. The cylinder is the primary air-water exchange pathway for this system. When the cylinder perforations enter the MIW pool in the bottom of the unit, the MIW is aggressively agitated and air bubbles are forced into it. This mechanism replicates natural aeration, eliminates the need for mechanical equipment, and is relatively unaffected by sediment, scaling, and related maintenance issues of alternative aeration technologies (Tsukamoto 2006).

The effectiveness of the RCTS^{TM} aeration allows for precipitation of Fe and Mn at a lower pH than conventional systems. In addition, the RCTS^{TM} system achieves almost 100% lime utilization due to the aggressive mixing and shearing forces present in the cylinder (Tsukamoto and Moulton 2005) which removes any coatings that tend to form on the lime particles. This typically results in lower lime consumption and less sludge generation than is typically experienced by conventional lime precipitation treatment systems due to the utilization of all of the available alkalinity in the introduced lime and less lime usage per unit of alkalinity required (Tsukamoto 2006).

Methods

A general arrangement of the RCTS^{TM} demonstration equipment is presented in Fig. 2. A photograph of the unit is provided in Fig. 3. Influent MIW was pumped into the reaction tank, where it was mixed with a metered dose of lime. The MIW flowed from the reaction tank through the rotating cylinder and into a polymer addition tank via gravity flow. Polymer was added to the polymer addition tank to assist solids-liquid separation. Process water was pumped from the polymer addition tank to a Geotube^{TM}. Effluent water flowed from the Geotube^{TM} into Cement Creek via overland gravity flow.

The sampling locations used during this demonstration include location S1, which was representative of influent MIW water quality, location S2, which was representative of RCTS^{TM} effluent water quality, and sample location S3, which was representative of Geotube^{TM} effluent water quality.

The demonstration RCTS^{TM} used to treat CC and American Tunnel AT MIWs used the same unit processes and process flow path. The only significant differences between the two configurations were the tank sizes used for the reaction tank and RCTS^{TM} effluent mixing tank. The CC demonstration treated MIW at much higher flow rates than the AT demonstration; therefore, the CC demonstration configuration included larger tank sizes for the reaction tank and effluent mixing tank. These tank size differences helped to maintain a comparable hydraulic retention time for the process water during the two demonstrations.

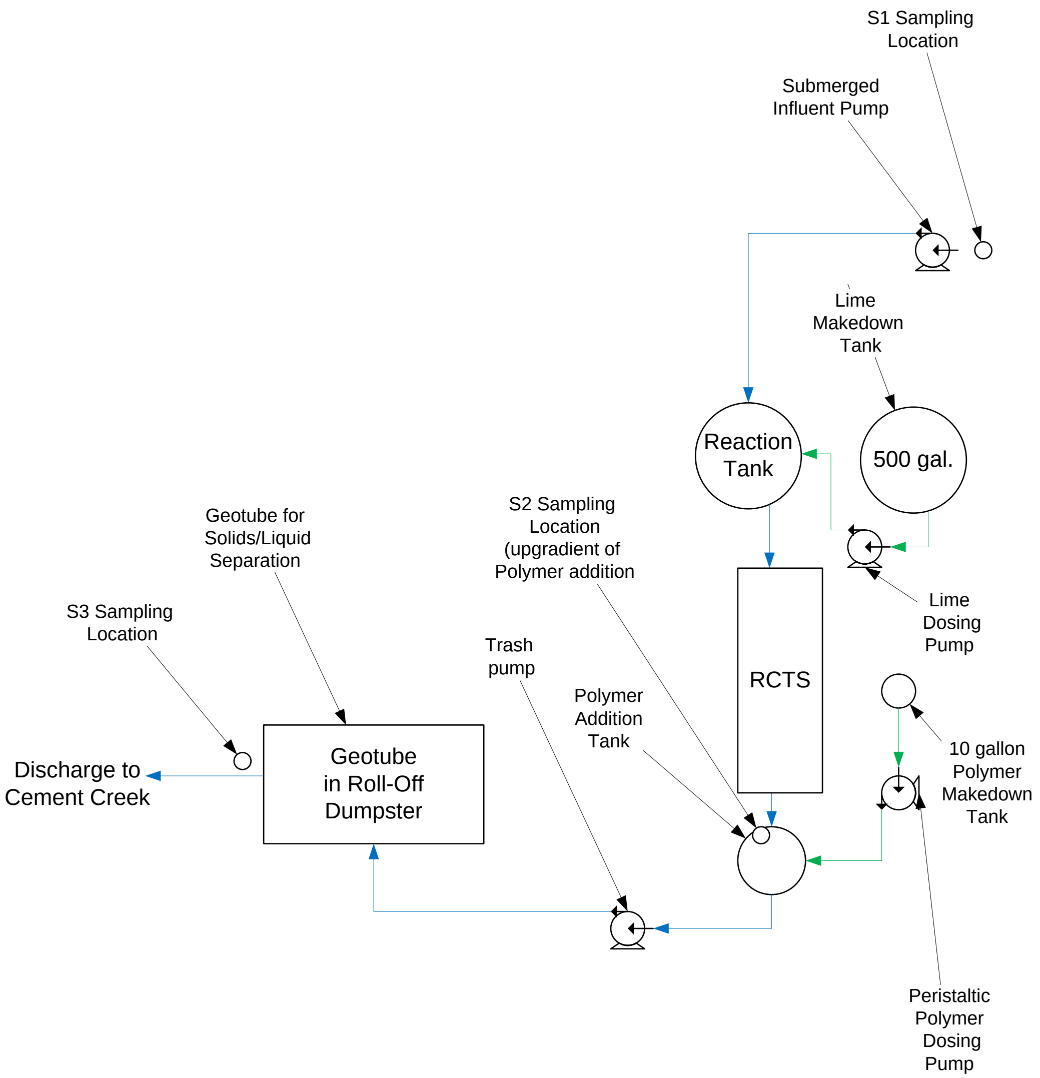

Figure 2: RCTS^{TM} Demonstration System Equipment General Arrangement

During RCTS^{TM} operations, the system was operated for at least eight hours per day. Typically, the system was set to operate at a desired flow rate using ball valves to restrict the output of the influent pumps. Once the system had achieved the desired flow, monitoring activities began. Field parameters including pH, temperature, oxidation-reduction potential, dissolved oxygen, and specific conductivity were monitored using a calibrated YSI 556 probe and data logger placed at the S2 sampling location. These field parameters were monitored to assess the consistency of the RCTS^{TM} effluent water quality. At least three samples were collected from the S2 location during each day of operations. These samples were intended to be “steady state” samples, collected during consistent RCTS^{TM} operations, based on field parameter measurements. Additional opportunistic samples were collected periodically throughout the demonstration to evaluate specific operating conditions. Aqueous samples were stored on-ice and transported to the EPA ORD laboratory in Cincinnati, Ohio under chain of custody protocols for analysis of target metals, alkalinity, and sulfates.

Figure 3: RCTS^{TM} Demonstration System at the Cement Creek Location

The sampling activities performed during this demonstration were complimented by several quality assurance and quality control activities, which included analysis of field blank samples (collected daily during the demonstration), blind duplicate samples, and comparison of dissolved and total metals concentrations reported for the same sample. These laboratory results indicated analytical errors did not significantly comprimise the data obtained during this demonstration.

Results and Discussion

Analytical results obtained from samples collected during the RCTS^{TM} demonstrations include dissolved and total metals concentrations. The maximum, minimum, and average dissolved concentrations corresponding to sample collected from the S2 sample location during the Cement Creek and American Tunnel demonstrations are summarized on Tables 1 and 2, respectively.

Table 1: Dissolved Concentrations reported for samples collected during the Cement Creek RCTS^{TM} demonstration

Parameter	Unit	Detection limit	Cement Creek Influent Concentration	-----Cement Creek Demonstration--- RCTS^{TM}-Effluent (S2) Concentrations-		
				Maximum	Minimum	Average
Field pH	s.u.	NA	3.5	9.6	8.0	9.1
Al	mg/L	0.058	10	2.1	0.17	0.91
Ca	mg/L	0.020	215	361	281	306
Cd	mg/L	0.002	0.030	0.0030	*<0.002*	*<0.002*
Cu	mg/L	0.003	1.6	0.22	*<0.003*	0.088
Fe	mg/L	0.015	0.52	2.7	*<0.015*	0.77
Mn	mg/L	0.005	19	5.3	*<0.005*	2.7
Pb	mg/L	0.006	0.021	0.0091	*<0.006*	*<0.006*
Zn	mg/L	0.005	13	2.1	0.38	1.1

Notes:

Italics indicate value was below the laboratory detection limits.
s.u. = standard units
NA = not available

Table 2: Dissolved concentrations reported for samples collected during the American Tunnel RCTS^{TM} demonstration

Parameter	Units	Detection limit	American Tunnel Influent Concentrations	American Tunnel Demonstration Effluent Concentrations		
				Maximum	Minimum	Average
Field pH	s.u.	NA	4.2	9.7	8.4	9.2
Al	mg/L	0.058	4.5	4.9	*<0.058*	0.38
Ca	mg/L	0.020	482	862	608	708
Cd	mg/L	0.002	0.0041	0.0043	*<0.002*	*<0.002*
Cu	mg/L	0.003	0.060	0.072	*<0.003*	0.0095
Fe	mg/L	0.015	150	150	0.023	11
Mn	mg/L	0.005	48	43	0.022	5.3
Pb	mg/L	0.006	0.022	28	*<0.006*	<0.006
Zn	mg/L	0.005	24	5.2	*<0.005*	2.5

Notes:

Italics indicate value was below the laboratory detection limits.
s.u. = standard units
NA = not available

Dissolved metals concentrations corresponding to samples collected from the S2 location (Fig. 2) were typically below the target regulatory criteria. Total concentrations reported for samples collected during treatment of Cement Creek and American tunnel MIWs are summarized on Tables 3 and 4. Total and dissolved metals concentrations were similar for the S2 samples.

Table 3: Total metals concentrations reported for samples collected from the S2 location during RCTS$^{\text{TM}}$ operations using Cement Creek MIW

Parameter	Units	Detection limit	Cement Creek Influent Concentrations	Cement Creek Demonstration Effluent Concentrations		
				Maximum	Minimum	Average
Al	mg/L	0.058	8.9	1.8	0.66	1.1
Ca	mg/L	0.020	204	340	284	303
Cd	mg/L	0.0017	0.030	*<0.0017*	*<0.0017*	*<0.0017*
Cu	mg/L	0.0026	1.6	0.14	0.0037	0.091
Fe	mg/L	0.015	30	0.67	*<0.015*	0.37
Mn	mg/L	0.0047	17	5.2	0.017	2.6
Pb	mg/L	0.0056	0.030	0.020	*<0.0056*	*<0.0056*
Zn	mg/L	0.0047	13	1.6	0.60	1.2

Notes:
Italics indicate value was below the laboratory detection limits.
s.u. = standard units
NA = not available

Table 4: Total metals concentrations reported for samples collected from the S2 location during RCTS$^{\text{TM}}$ operations using American Tunnel MIW.

Parameter	Units	Detection limit	American Tunnel Influent Concentrations	American Tunnel Denonstration Effluent Concentrations		
				Maximum	Minimum	Average
Al	mg/L	0.058	4.6	5.2	*0.029*	0.40
Ca	mg/L	0.020	465	714	619	646
Cd	mg/L	0.002	0.0043	<0.002	*<0.002*	*<0.002*
Cu	mg/L	0.003	0.032	0.047	*0.0013*	0.0087
Fe	mg/L	0.015	169	153	*0.0074*	11
Mn	mg/L	0.005	52	47	0.028	5.5
Pb	mg/L	0.006	0.013	0.19	*<0.006*	0.017
Zn	mg/L	0.005	21	20	0.35	2.0

Notes:
Italics indicate value wass below the laboratory detection limits.
s.u. = standard units
NA = not available

Established discharge water quality criteria were not available for the American Tunnel discharge. State of Colorado Surface water quality criteria for Cement Creek and USEPA water quality criteria for surface water were used as on a comparative basis to evaluate analytical data from the S2 sampling location. These standards were used for the purposes of the technology demonstration, and were not considered potential discharge water quality criteria. Discussions of the data relating to the constituents of concern follow.

Aluminum– Cement Creek contained higher Al concentrations (Fig. 4) (~10 mg/L) than the American Tunnel discharge (~4 mg/L). These influent concentrations are above the Animas River Water quality Standard of 1.49 mg/L, the EPA criteria maximum concentration (CMC) of 0.750 mg/L, and the EPA criteria continuous concentration (CCC) of 0.087 mg/L. During treatment of both the AT and CC MIWs, S2 Al concentrations were consistently below the Animas River Standard of 1.49 mg/L. Ignoring outliers, one total Al concentration and two dissolved Al concentrations were above the Animas River standard. These elevated concentrations were observed during the CC demonstration (samples CC-S2-SS2-200 and S2-SS3-200). These reported concentrations were 1.7 and 2.1 mg/L, less than 1 ppm above the water quality goal of 1.49 mg/L. Five of the CC S2 sample Al concentrations were below the EPA CMC freshwater standard of 0.75 mg/L; all of the CC samples had Al concentrations detected at concentrations above the EPA CCC of 0.087 mg/L. One sample collected during the AT demonstration (sample AT-S2-SS2-100) had a reported Al concentration (0.064 mg/L) above the detection limit (0.06 mg/L). This concentration was below the EPA CCC freshwater criterion of 0.087 mg/L.

The difference between AT and CC RCTS^{TM} effluent Al concentrations is readily apparent on Fig. 4. One possible explanation is the difference in influent concentrations. AT influent, Al concentrations were about half the influent CC concentrations (4.5 vs 10 mg/L dissolved, 4.6 vs. 12 mg/L total). Under the Gladstone site test conditions, the RCTS^{TM} appears to be more efficient at removing lower concentrations of Al.

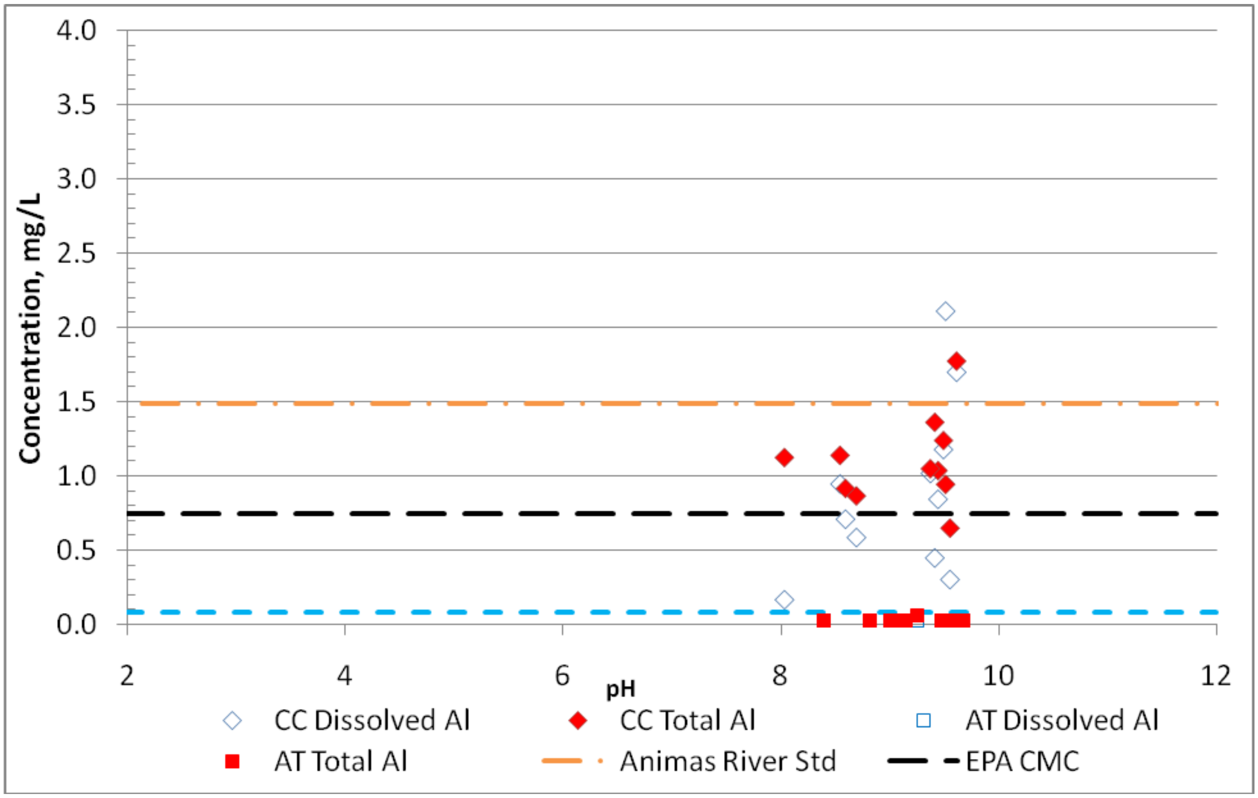

Figure 4. Aluminum concentrations observed in samples collected from the S2 location during the RCTS^{TM} demonstration versus sample pH. Samples collected from the S2 location contained sample pH values greater than 6.

<u>Cadmium</u> – CC influent Cd concentrations ranged from 0.030 mg/L to 0.032 mg/L (Fig. 5.) AT influent dissolved and total Cd concentrations were 0.0041 mg/L. Cadmium was detected above the laboratory detection limit in one RCTS^{TM} effluent sample collected from the S2 location (sample CC-S2-SS3-300) at a concentration of 0.0030 mg/L. The laboratory detection limit of 0.002 mg/L is greater than the Animas River Standard (0.0007 mg/L) and EPA CCC (0.00025 mg/L) water quality criteria.

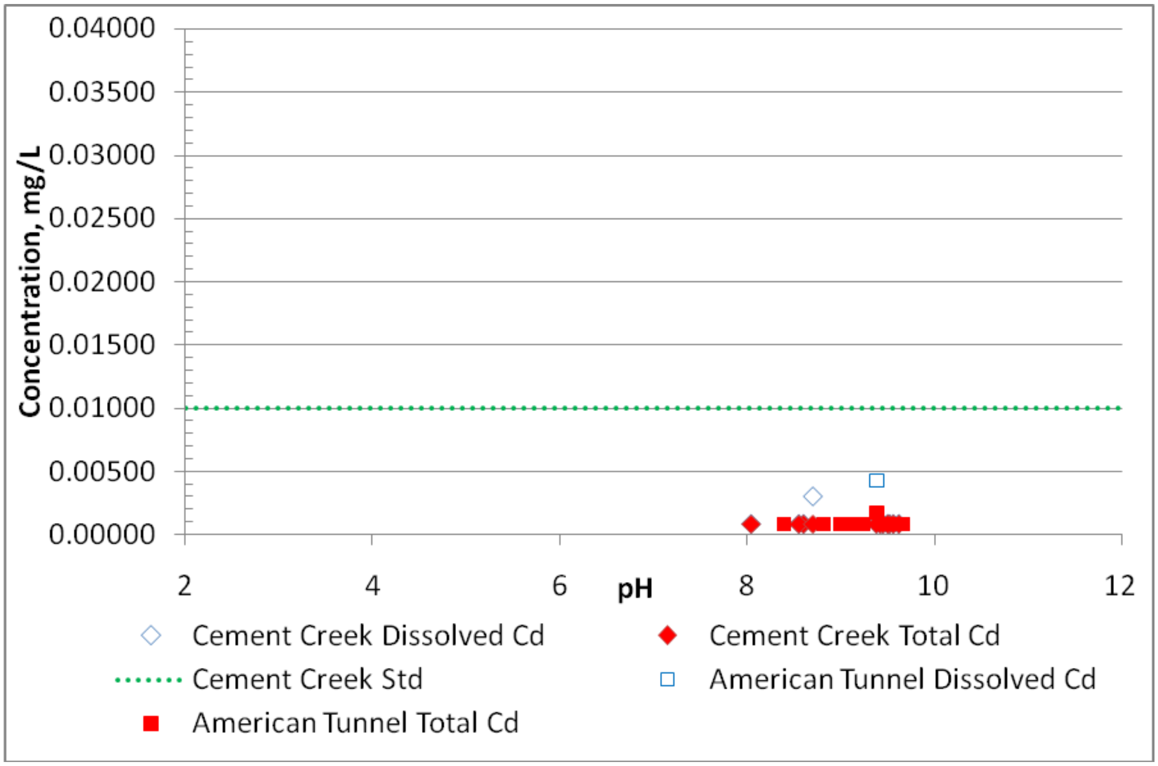

Figure 5: Cadmium concentrations reported for samples collected from the S2 location vs. pH

Copper – Influent CC dissolved Cu concentrations ranged from 1.56 to 1.78 mg/L (Fig. 6). Influent AT dissolved and total Cu concentrations were virtually identical; 0.06 and 0.03 mg/L, respectively. Copper concentrations collected at the S2 location ranged from below the laboratory detection limit of 0.003 mg/L to 1.78 mg/L during the CC demonstration, and from below the laboratory detection limit to 0.072 mg/L during the AT demonstration. Twenty-eight AT and CC S2 samples contained concentrations below the Animas River water quality standard of 0.016 mg/L. The remaining analyses contained concentrations greater than the Animas River Standard but less than the Cement Creek water quality standard of 0.2 mg/L, with one exception. Sample CC-S2-SS2-200 contained a dissolved concentration of 0.22 mg/L, which is above the Cement Creek standard. All of the S2 Cu analysis values were below the Human Health Consumption of Water and Organism Standard of 1.3 mg/L.

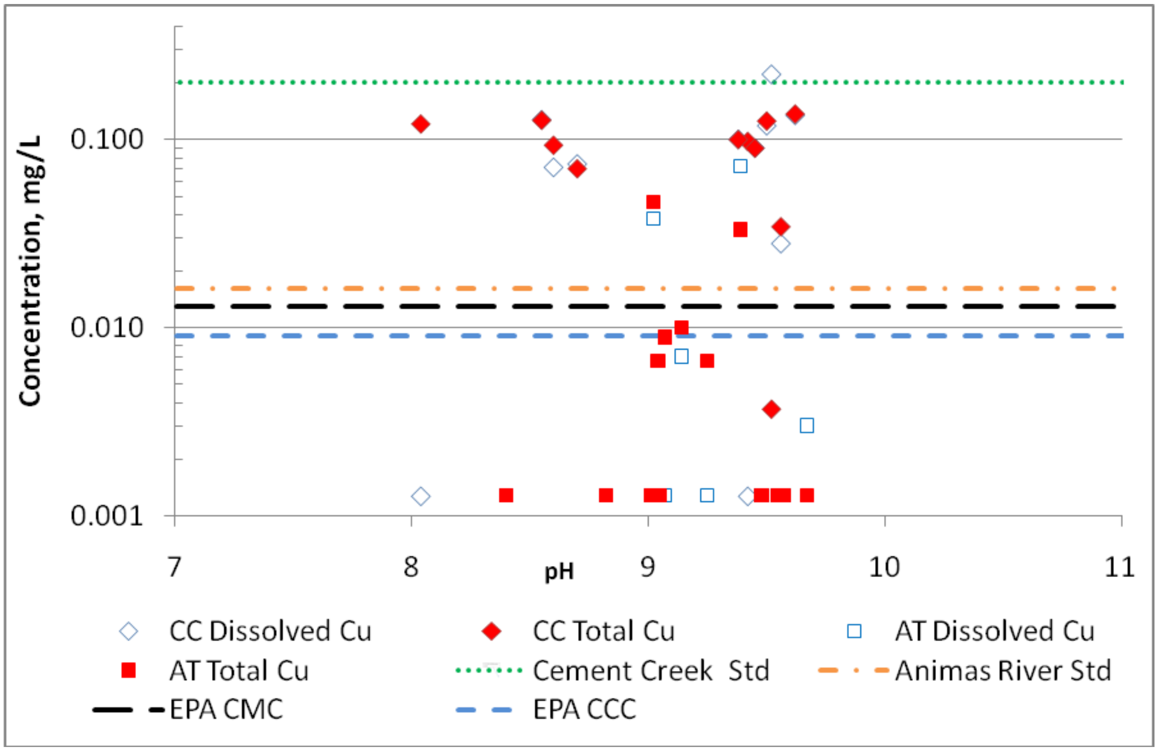

Figure 6: Copper concentrations reported for samples collected from the S2 location vs. pH

Iron – During the CC demonstration, S2 Fe concentrations varied from below the laboratory detection limit of 0.01 mg/L to 3.5 mg/L (Fig. 7). Ignoring the outlier data, AT demonstration S2 concentrations ranged from below the laboratory detection limit to 2.22 mg/L (ignoring the outlier Fe concentration of 153 mg/L). Influent CC Fe concentrations ranged from 0.5 (dissolved Fe concentration from CC-S1-100) to 58 mg/L, influent reported AT Fe concentrations were 150 mg/L dissolved, 169 mg/L total Fe. Three samples collected from the S2 location during the CC demonstration had reported dissolved Fe concentrations greater than the Animas River water quality standard of 1.623 mg/L, and the EPA CCC (1 mg/L). One sample collected during the CC demonstration had a reported Fe concentration greater than the Animas River Water Quality Standard. During the AT demonstration, three S2 samples contained dissolved concentrations of Fe greater than the Animas River Standard and the EPA CCC; one total Fe concentration was above these standards.

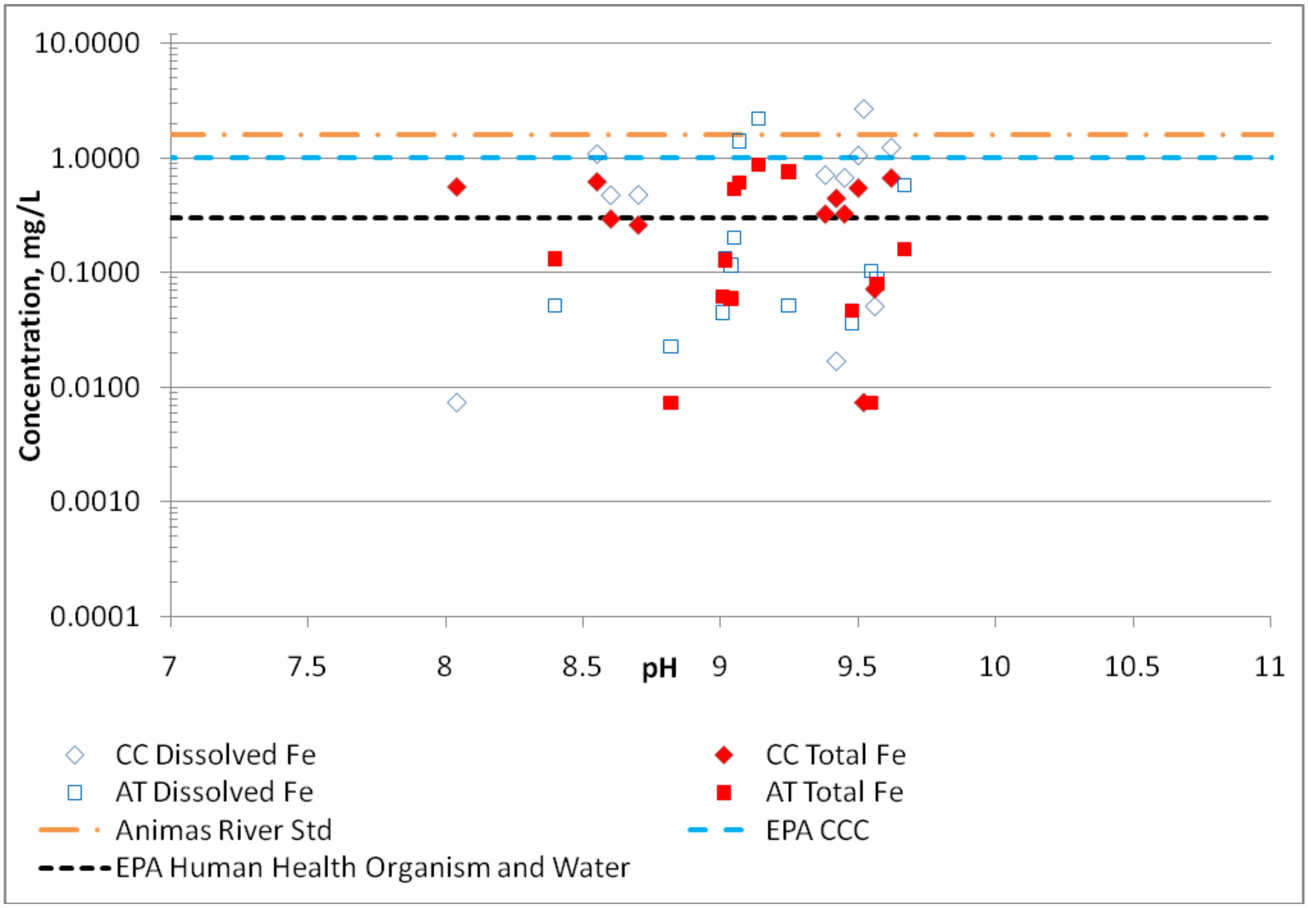

Figure 7: Iron concentrations reported for samples collected from the S2 location vs. pH

Lead – Influent lead concentrations reported during the CC demonstration varied from 0.021 to 0.11 mg/L (Fig. 8). During the AT demonstration, influent Pb was 0.013 mg/L (total), dissolved Pb was reported as 0.022 mg/L. During the CC demonstration, five analyses performed on samples collected from the S2 location yielded Pb concentration values greater than the laboratory detection limit of 0.0055 mg/L. During the AT demonstration, seven analyses performed on samples collected from the S2 location contained Pb concentrations greater than the laboratory detection limit. During the CC demonstration, one total concentration value (CC-S2-SS1-100) was above the Cement Creek Water Quality Standard of 0.1 mg/L; one AT sample (AT-S2-OPP3-60) contained total and dissolved Pb concentrations greater than the Cement Creek standard of 0.1 mg/L. These reported Pb concentrations for sample AT-S2-OPP3-60 were also greater than Pb concentrations reported for the AT-S1-60 sample.

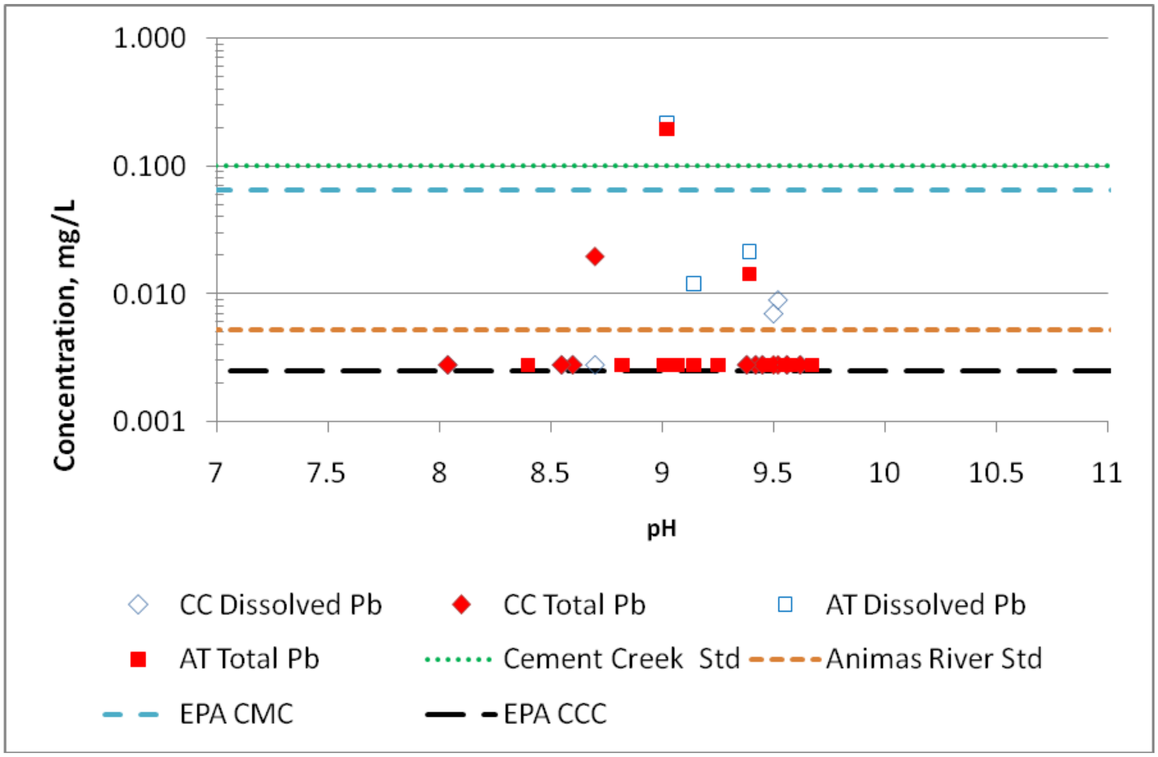

Figure 8: Lead concentrations reported for samples collected from the S2 location vs. pH

<u>Manganese</u> – Influent Mn concentrations ranged from 17 to 18 mg/L during the CC demonstration, and were 48 mg/L (dissolved concentration) and 52 mg/L (total concentration) during the AT demonstration (Fig. 9). Manganese concentrations reported for samples collected from the S2 location varied from below the laboratory detection limit of 0.005 mg/L to 5.6 mg/L during the CC demonstration, and from below the laboratory detection limit to 47 mg/L (AT-S2-SS1-100). At the AT site, RCTS^{TM} effluent concentrations were frequently observed to be greater than the Animas River water quality standard of 2.08 mg/L. As plotted on Fig. 9, the elevated Mn concentrations were observed across a sample pH range of 8 to 9.8. The samples with elevated Mn concentrations are not easily comparable to other AT & CC samples collected at similar pH values, which did not contain high Mn concentrations. From the Cement Creek S2 sample location data set, 22 out of 25 Mn analyses performed on S2 samples (88%) were above the Animas River water quality criteria. However, 10 of the 28 reported Mn concentrations corresponding to samples collected from the AT sample location (36%) were above the Animas River standard. This suggests that the RCTS^{TM} was more efficient at treating the higher influent Mn concentration found in the AT MIW.

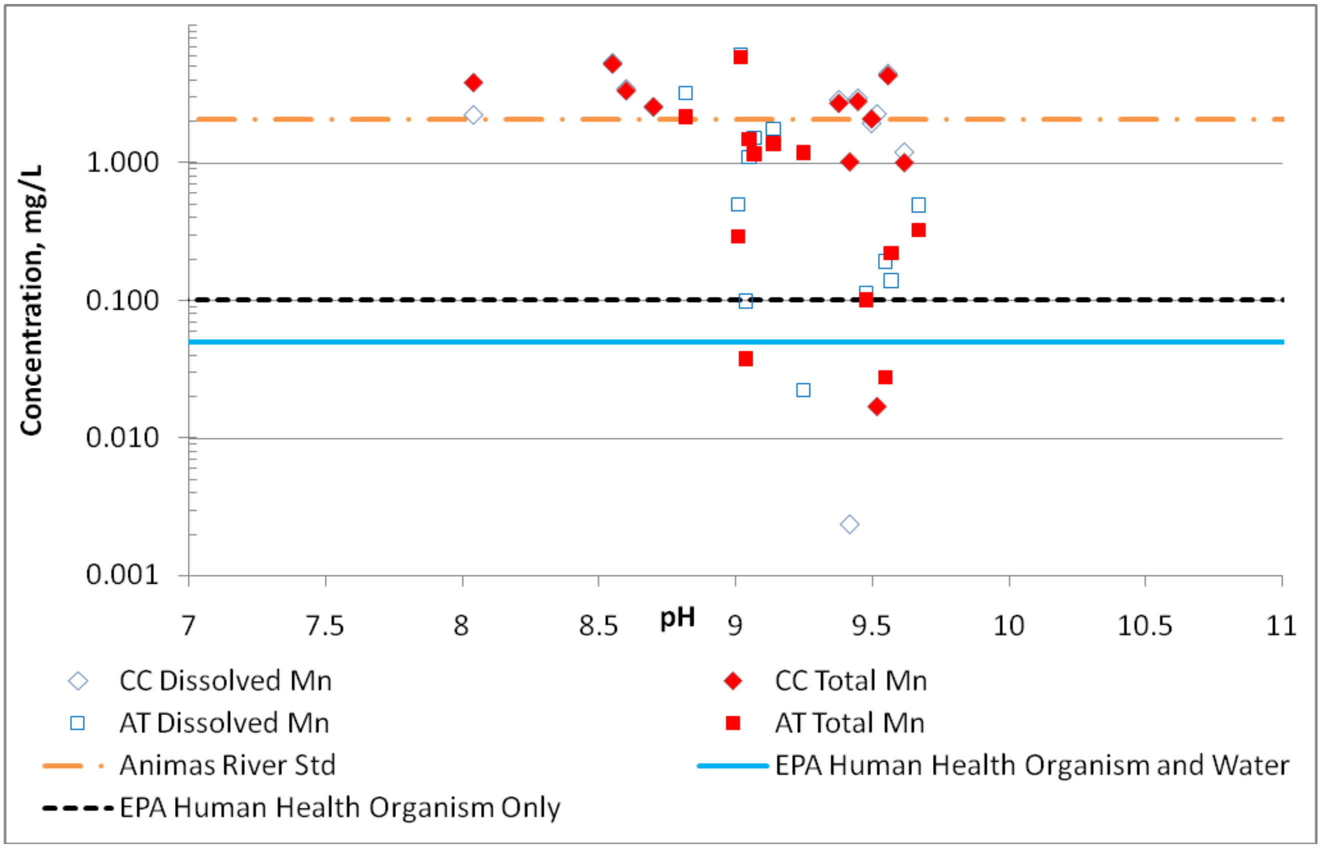

Figure 9: Manganese concentrations reported for samples collected from the S2 location vs. pH

Zinc – Figure 10 presents a graph of reported Zn concentrations vs. pH for samples collected from the S1 and S2 locations during the AT and CC demonstrations. Concentrations corresponding to low pH values represent untreated MIW. During the CC demonstration, influent total and dissolved Zn concentrations were 13 mg/L. During the AT demonstration, influent Zn concentrations were 24 mg/L (dissolved) and 21 mg/L (total). This analytical discrepancy for Zn was not resolved as of the date of this report. This and other similar occurrences in the analytical data set do not affect the study findings. Samples at elevated pH (8-10) reflect S2 and S3 sample locations. Reported dissolved and total Zn concentrations corresponding to samples collected from the S2 location during the AT and CC demonstrations were consistently greater than the laboratory detection limit of 0.005, the EPA CCC (0.12 mg/L). The Animas River Standard of 0.29 mg/L, with one exception, sample AT-S2-SS2-100, which had a reported dissolved Zn concentration below the laboratory detection limit of 0.05 mg/L. All of the total and dissolved metals analyses performed on samples collected from the S2 location during the AT and CC demonstrations resulted in concentrations below the Cement Creek water quality criteria (2 mg/L).

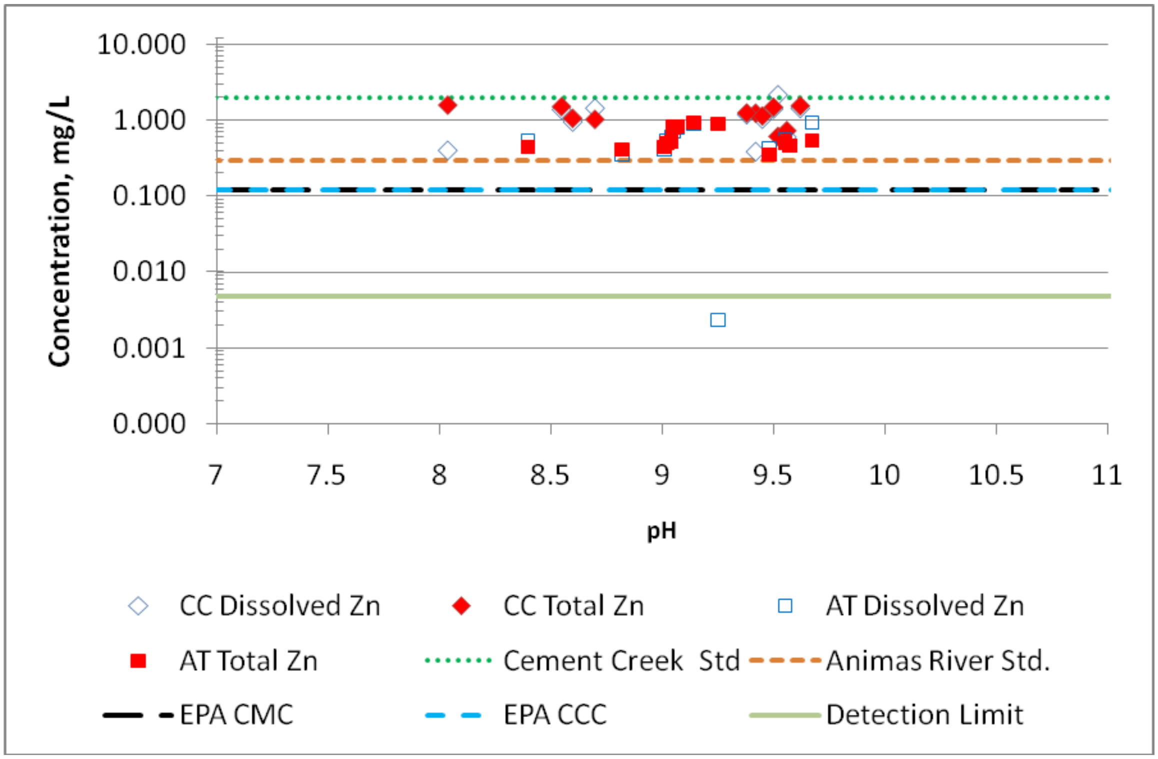

Figure 10: Zinc concentrations reported for samples collected from the S2 location vs. pH

<u>Cement Creek Opportunistic Sample Results</u>

Two opportunistic samples were collected from the RCTS^{TM} effluent sampling location (S2) during RCTS^{TM} operations using Cement Creek MIW. Sample CC-S2-OPP1-100 was collected to be representative of system startup conditions. This sample was collected immediately after the RCTS^{TM} had reached a consistent pH. The opportunistic sample analytical results were similar to the laboratory results corresponding to the steady state samples.

A second opportunistic sample was collected from location S2 during RCTS^{TM} operations at a flow rate of 400 gpm. This sample was collected to evaluate the demonstration system performance at the maximum flow rate possible at the CC site with the equipment on-hand. The laboratory results from this opportunistic sample (CC-S2-Opp2-400) were compared to the laboratory results obtained from steady state samples collected at a flow rate of 300 gpm. Laboratory results from the opportunistic sample were similar to results for the steady state samples, suggesting that RCTS^{TM} performance was similar at 400 and 300 gpm flow rates.

American Tunnel Opportunistic Sample Results

During the AT MIW treatment, five opportunistic samples were collected from the RCTS^{TM} effluent (location S2). Sample AT-S2-OPP3-60 was collected as a sample representative of a lower pH than the steady state samples collected at a flow rate of 60 gpm. This sample was collected using identical methodology to the steady state samples. The opportunistic sample results were compared to the laboratory results from steady state samples collected at a flow rate of 60 gpm. These results suggest that the lower pH of the opportunistic sample contained total and dissolved Pb concentrations (0.22 and 0.19 mg/L) which were significantly higher than the steady-state Pb samples (less than laboratory detection limits). Copper, Fe, and Mn concentrations observed in the opportunistic sample were also higher than steady-state effluent concentrations. This data confirms operational pH plays a major role in determining effluent metals concentrations.

An opportunistic sample (AT-S2-OPP4-100) was collected during the 100 gpm AT RCTS^{TM} demonstration. This sample was collected as a duplicate of Sample AT-S2-SS2-100, but was allowed to settle in a 5-gallon (20 L) bucket for 24 hours before collecting analytical sample volumes. The opportunistic sample contained lower concentrations of dissolved Mn, Fe, Al, and Zn. The increased settling time improved RCTS^{TM} effluent water quality.

Three opportunistic samples were collected during the AT demonstration at a flow rate of 30 gpm. These samples were collected at incrementally lower pH values to evaluate the effects of operational pH on effluent metals concentrations. Total and dissolved Cd, Cu, and Pb concentrations were below the laboratory detection limits in the opportunistic samples, which was consistent with the steady-state sample results. Iron and Mn concentrations increased as the operational pH decreased, suggesting that the higher operating pH results in better Fe and Mn removal.

Two composite sludge samples were collected from the Geotubes^{TM} for analysis of SPLP and TCLP metals. Table 5 presents a summary of laboratory results from the TCLP and SPLP procedures. TCLP results indicate that Ba and Cd were detected in the CC composite sludge sample at concentrations of 0.117 and 0.198 mg/L, respectively. Barium was detected in the AT composite sludge sample at a concentration of 0.052 mg/L during TCLP analysis. These concentrations are below the TCLP concentration limits of 100 mg/L for Ba and 1.0 mg/L for Cd. Other target metals were not detected at concentrations above the laboratory detection limits. These laboratory results indicate the sludge generated by the RCTS^{TM} either at the CC or AT sites would not be considered a hazardous waste based on toxicity characteristics.

Table 5: Analytical Sludge Sample Results

Analyte	Laboratory MDL	Target TCLP Concentration	Target SPLP Concentration	Cement Creek Composite Sample		American Tunnel Composite Sample	
	mg/l	mg/l	mg/l	TCLP	SPLP	TCLP	SPLP
Arsenic	0.04	5	5	<0.04	<0.04	<0.04	<0.04
Barium	0.003	100	100	0.117	<0.003	<0.003	<0.003
Cadmium	0.005	1	1	0.198	<0.005	<0.005	<0.005
Chromium	0.01	5	5	<0.01	<0.01	<0.01	<0.01
Lead	0.04	5	5	<0.04	<0.04	<0.04	<0.04
Mercury	0.0002	0.2	0.2	<0.0002	<0.0002	<0.0002	<0.0002
Silver	0.01	5	5	<0.01	<0.01	<0.01	<0.01
Selenium	0.04	1	1	<0.04	<0.04	<0.04	<0.04

Notes:

- mg/l = milligrams per liter
- ND = target analyte was not detected at a concentration above the laboratory method detection limit.
- MDL = method detection limit
- TCLP = toxicity characteristic leaching procedure
- SPLP = synthetic precipitation leaching procedure

Cold acidity was measured in the field by titrating Cement Creek and American Tunnel untreated water with 0.1N NaOH to a pH of 9.5. The cold acidity from Cement Creek on 8-20-08 was measured at 220 mg/L $CaCO_3$. Acidity was also estimated at 205 mg/L $CaCO_3$ using AMD Treat. Lime consumption was measured daily. Lime consumption during periods of consistent treatment without changes in flow or dramatic changes in pH was used for the calculations below.

On 8-20-08 (100 gpm), lime consumption was measured over a 430 minute period between 10:50 and 16:00. During that time ~31,000 gallons of water was treated and ~44 lbs of lime was consumed which corresponds to an average lime consumption of 169 mg/L $Ca(OH)_2$ 230 mg/L $CaCO_3$. This translates to 96% efficiency. On 8-21-08 (200 gpm), lime consumption was measured over a 235 minute period between 12:05 and 16:00. During that time ~71,000 gallons of water was treated and ~110 lbs of lime was consumed which corresponds to an average lime consumption of 185 mg/L $Ca(OH)_2$ or 250 mg/L $CaCO_3$. This translates to 88% efficiency. On 8-22-08 (300 gpm), lime consumption was measured over a 360 minute period between 9:10 and 15:10. During that time ~108,000 gallons of water was treated and ~135 lbs of lime was consumed which corresponds to an average lime consumption of 149 mg/L $Ca(OH)_2$ or 201 mg/L $CaCO_3$. This translates to 109% efficiency.

The cold acidity from the American Tunnel on 8-25-08 was measured at 630 mg/L $CaCO_3$. Acidity was also estimated at 675 mg/L $CaCO_3$ using AMD Treat. On 8-25-08 (60 gpm), lime consumption was measured over a 490 minute period between 9:00 and 17:10. During that time ~29,400 gallons of water was treated and ~135 lbs of lime was consumed which corresponds to an average lime consumption of 550 mg/L $Ca(OH)_2$ 743 mg/L $CaCO_3$. This translates to 85% efficiency. On 8-26-08 (100 gpm), lime consumption was measured over a 360 minute period between 8:45 and 14:45. During that time ~36,000 gallons of water was treated and ~147 lbs of lime was consumed which corresponds to an average lime consumption of 489 mg/L $Ca(OH)_2$ 660 mg/L $CaCO_3$. This translates to 95% efficiency. On 8-27-08 (30 gpm), lime consumption was measured over a 310 minute period between 7:10 and 12:20. During that time ~9,300 gallons of water was treated and ~39 lbs of lime was consumed which corresponds to an average lime consumption of 502 mg/L $Ca(OH)_2$ 678 mg/L $CaCO_3$. This translates to 93% efficiency.

The average lime efficiency at Cement Creek was 98% while the average lime efficiency at the American Tunnel was 91%. The increase in lime consumption at the American Tunnel is likely due to the higher operating pH that was necessary to remove Mn.

The lime consumption rates of the RCTS^{TM} were also compared to the lime consumption rates experienced by the Argo Tunnel water treatment facility in Idaho Springs, Colorado, and the Summitville Water Treatment System at the Summitville Superfund Site in Colorado. Both the Argo and Summitville Water Treatment Systems are conventional active treatment systems, which use lime addition to reduce MIW metals concentrations. Water quality data for the Argo and Summitville water treatment systems are compared to the RCTS^{TM} influent water quality data in Table 5. Acidity values presented in Table 5 were calculated using AMD Treat software and the water quality data presented in Table 5. The Argo and Summitville influent water qualities were similar to the RCTS^{TM} influent data, indicating the direct comparison of lime dosing rates is reasonable.

In August 2008, the Argo water treatment plant treated an average MIW flow rate of 271 gpm, and consumed an average hydrated lime mass of 3,303 pounds per day, which translates into a lime dose rate of 1,000 mg/L $Ca(OH)_2$ or 1350 mg/L $CaCO_3$. The calculated acidity using AMD Treat is 759 mg/L $CaCO_3$; this translates to 56% efficiency. During 2008, the Summitville water treatment facility treated 321,672,819 gallons of MIW, while consuming 1,800,000 pounds of lime, resulting in a lime dose rate of 9,600 mg/L $Ca(OH)_2$ or 12,960 mg/L $CaCO_3$. The calculated acidity using AMD Treat is 794 mg/L $CaCO_3$. The RCTS^{TM}, appears to require significantly less lime than these two typical conventional systems.

Samples were taken from the effluent of the RCTS^{TM} unit at Cement Creek and the American Tunnel. Untreated samples were then taken and titrated to the same pH with the same lime slurry. Shown in Fig. 11 below are a 1L titrated sample from Cement Creek pH 9.05 (left) and a 1L RCTS effluent sample at pH 9.5 (right). The titrated sample settled to a final volume of 70 ml and the RCTS sample settled to a final volume of 55 ml in 75 minutes.

10 minutes 20 minutes 75 minutes

Figure 11: Sludge Production Observed during the Cement Creek Demonstration.

Figure 12 presents similar sludge observations made during the American tunnel demonstration A 1L titrated sample from the American Tunnel pH 9.21 with 20 mL of 3% peroxide (left), a 1L titrated sample from the American Tunnel pH 9.18 (center) and a 1L RCTS effluent sample at pH 9.21 (right). The titrated sample settled with peroxide settled to a final volume of 145 ml, the titrated sample settled to a final volume of 150 ml and the RCTS sample settled to a final volume of 100 ml in 120 minutes. The American Tunnel MIW generated more sludge during the RCTS demonstration than the Cement Creek MIW. This is likely due to the increased acidity and metals concentrations, which resulted in decreased lime efficiency and increased required lime dose for RCTS treatment of the American Tunnel MIW.

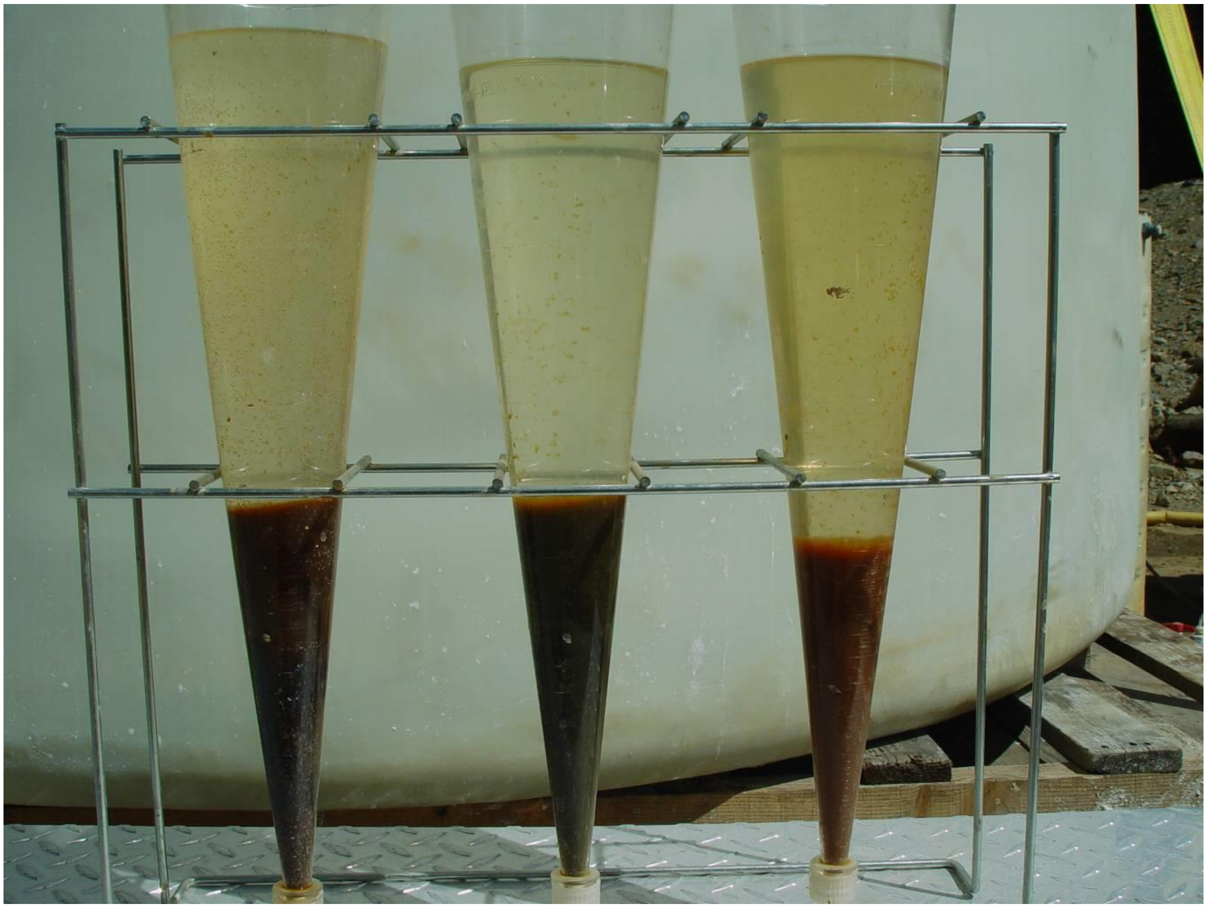

Figure 12: Sludge volume after 120 minutes of settling for American Tunnel Samples.

The laboratory results corresponding to samples collected from the S2 location suggest that the RCTS^{TM} is capable of meeting the applicable water quality criteria for the constituents of concern (Table 1). Multiple effluent RCTS^{TM} samples contained reported metals concentrations below the target water quality criteria for each of the constituents of concern. Fluctuations in the RCTS^{TM} effluent Mn concentrations indicate there may be a reliability issue concerning the RCTS^{TM} ability to remove Mn below the Animas Water Quality Standard of 2.078 mg/L.

Installation of a permanent RCTS™ and accompanying settling ponds could help to improve the consistency in the effluent concentrations.

Samples collected from the S3 location routinely contained TSS concentrations greater than 50 mg/L. Accordingly, there was a significant difference observed between total and dissolved concentrations. The elevated TSS concentrations are believed to be due to solids passing through the Geotube™ material. The total metals concentrations reported for S3 samples were greater than metals concentrations reported for samples collected from the S2 location. The S2 samples were allowed to settle, minimizing the TSS present in the sample water. The dissolved concentrations observed at the S3 location are a more accurate reflection of the process performance. The elevated total metals and TSS concentrations observed at S3 suggest the Geotube™ might have benefitted from pre-conditioning with an inert material such as diatomaceous earth. Regardless, this technique was an adequate low-cost surrogate for a settling pond to collect process sludge samples. Cadmium detected in the CC sludge composite sample was within one order of magnitude of its TCLP limit, representing the greatest threat that an exceedance might impose on the receiving stream.\

In summary, the RCTS™ demonstration suggests that the technology is capable of efficient MIW treatment. The RCTS™ appeared to be capable of maintaining steady-state operating conditions with minimal operator intervention during the RCTS™ demonstrations. Combined with a settling pond for solids removal, the RCTS™ should be a reasonable water treatment technology to implement in the Gladstone, Colorado vicinity.

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