Emergency Treatment of Acid Mine Drainage at the Leviathan Mine with the Rotating Cylinder Treatment System (*RCTS™*)

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Abstract

Acid mine drainage (AMD) typically contains elevated concentrations of dissolved metals, including ferrous iron and manganese. Lime precipitation is the most common method of treating AMD. The oxidation of ferrous iron and manganese is a common component to most lime treatment systems because the oxidized forms of iron and manganese are precipitated from solution more readily and at a lower pH than the reduced forms. This oxidation is typically accomplished by pumping air with compressors and mixing the air, lime and water with agitation mixers in large reaction tanks. Although this method of treatment is effective, it requires significant power and a large amount of space to house the reaction tanks.

Ionic Water Technologies' (IWT), Rotating Cylinder Treatment System (RCTS™) (US Patent No. 7,011,745) utilizes a shallow trough like cell (that contains the water being treated) and a rotating cylinder to transfer oxygen and agitate the air/water/lime mixture. When compared with conventional systems it requires less power and less space and is more effective at mixing which results in lower chemical costs. In addition, the oxidation reaction times are shortened and treatment can be achieved at a lower pH.

A mobile RCTS™ treatment system was rapidly mobilized for emergency treatment of AMD at the Leviathan Mine, located in California, USA. This remote site lies on the eastern slope of the Sierra Nevada Mountains at approximately 2100 meters and has no permanent power source on site. AMD which flows from an adit and pit under drain system is typically stored over the winter months in a series of containment ponds. When the snow melts and the roads become clear, a treatment system is seasonally operated to treat the water contained in the storage ponds. The winter of 2005/2006 was a particularly wet year which resulted in the containment ponds filling prematurely with a combination of AMD and snowmelt. The goal of this project was to mobilize a treatment system through approximately 19 kilometres of un-maintained road through snow as deep as 2 meters in order to prevent untreated water from flowing to nearby Leviathan Creek.

IWT and TKT Consulting, LLC "now IWT" was informed to start the mobilization process on April 5, 2006. The road was inspected on April 6 and was plowed to remove snow on April 9. Eighteen pallets of lime were delivered to the Nevada/California border and were shuttled to the site via four-wheel drive equipment on April 12 and 13. The RCTS™-HS unit and lime delivery system was mobilized to the site on April 14. Treatment began at 11:30 a.m. on April 14 and by 10 a.m on April 15 the discharge pH was 8.3 s.u.. AMD was continually treated at a flow rate of up to 1220 lpm over a period of approximately 85 days during which time the influent chemistry changed dramatically.

1 Introduction

Acid mine drainage (AMD), contaminated with dissolved metals has become an environmental problem of considerable concern. The most used method to treat this problem is lime precipitation. The objective of typical lime precipitation is to raise the pH of the water and oxidize the metals and precipitate them from solution. Oxidized iron and manganese precipitate at lower pHs than reduced forms. Although effective, typical lime precipitation processes require significant amounts of power to run the compressors and mixers that are necessary for oxidation and mixing. In addition, a large amount of space is required to house the reaction tanks where the oxidation and mixing occurs.

Ionic Water Technologies applies the same general principles to achieve water treatment objective through its patented Rotating Cylinder Treatment System "*RCTS*^{TM}" (US Patent No. 7,011,745). This system utilizes a shallow trough like cell that contains a rotating cylinder which transfers oxygen and agitates the air/AMD/lime mixture. The benefits of this technology is that it requires less energy, less space and it is more effective in mixing and dissolving lime, which results in a lower cost of reactants. In addition, the oxidation reaction times are reduced and the treatment can be achieved at a lower pH.

Emergency treatment of AMD was required at the Leviathan Mine, California, USA, 2100 meters above sea level and with no permanent power source at the site. The objective was to treat water before it flowed into nearby Leviathan Creek. The RCTS-30HS unit and a lime delivery system were mobilized to the site on April 14, 2006. Treatment begun at 11:30 a.m. of that same day and by 10:00 a.m. of next day the discharge pH was 8.3 s.u.

2. Methodology

The Leviathan Mine is a non-operating open-pit sulfur mine high on the eastern slope of the Sierra Nevada, in Alpine County, California, USA. The ponds at the Leviathan Mine have been utilized to contain water contaminated with AMD since their construction in 1985. Pond 1, Pond 2 North and Pond 2 South (the upper ponds) drain into Pond 3 during an overflow event. When full, Pond 3 overflows to Leviathan Creek. All of the ponds receive direct precipitation, most of which comes in the form of snow during the winter. In addition, the upper ponds receive acidic drainage from the adit and pit under-drain (PUD).

The winter of 2004-2005 was the first winter with above average rainfall since the ponds were drained down and treated in the early 2000's. This resulted in substantial increases of the flows of the adit and PUD and also increased the direct precipitation to the ponds. In 2005, TKT was contracted to provide emergency treatment at pond 3. At the beginning of the 2005 Emergency Treatment, it was estimated that Pond 3 contained approximately 900,000 gallons of AMD at pH 2.8 s.u.. This AMD contained high concentrations of aluminum and low concentrations of iron. In 2005, the AMD in Pond 3 was neutralized and approximately 600,000 gallons were discharged, while the remainder was left in the pond to evaporate. The sludge that was generated in 2005 was not removed and remained in the pond at the time of the emergency treatment in 2006.

In 2006 TKT and IWT were again contract to provide emergency treatment. The water table at the mine site remained elevated from the previous high water year. In addition, the winter of 2006 was another high precipitation year. It was unknown at the start of treatment how much AMD would need to be treated to prevent discharge of untreated AMD to Leviathan Creek.

2.1 Types of AMD

More than 28 million litres of AMD were treated over 85 days of emergency treatment. The treatment began on April 14, 2006 and ended in July 10, 2006. The AMD varied in composition over time and for simplicity we have divided it into three categories according to the chemistry of the AMD.

2.1.1 Initial AMD

The AMD that was treated initially, was mainly ice and snow melt that was contained in pond 3 and that overflowed from the surfaces of the upper ponds. This AMD was low in metals and sulfate concentrations but contained some dissolved reduced iron. We were able to treat this AMD at a high rate because the acidity was low and ferrous iron concentration and oxygen consumption was relatively low. The rate at which this AMD could be treated was controlled by the ability to mix the AMD in pond 3 with the treated alkaline *RCTS*^{TM} effluent.

2.1.2 Mixture of surface overflow and AMD siphoned from Pond 1

Once the ice melted from the surface of the ponds, the stratified AMD mixed and the AMD that spilled over from the upper ponds increased in metals, sulfate and TDS concentrations and acidity. AMD was also conveyed from the upper ponds to the lower ponds through a siphon hose, in addition to the overflow. This combined AMD was the most difficult to treat at higher flow rates. The iron in the AMD during this stage of treatment was mostly in the reduced form and the concentration was high, the acidity and oxygen consumption were also high. The ability to oxidize iron in this AMD controlled the rate at which the AMD could be treated.

2.1.3 AMD siphoned from Pond 1

As time went on, the pond took on oxygen prior to treatment and the iron within the ponds began to oxidize. Towards the end of treatment the majority of the iron was oxidized, however the acidity remained high. We were able to treat this AMD at a high rate due to the low oxygen consumption. The rate at which lime could be added controlled the rate at which this AMD could be treated.

The following table provides a summary of the characteristics of the AMD treated.

Table 1 Characterization of the three types of AMD encountered on site

AMD Type	Dates Encountered	Description	Average Treatment Rate	Iron	Aluminum
Initial AMD (Ponds Stratified)	April 14 to May 8 (21 Days)	AMD was mostly rain and snow melt with low acidity and low metals concentrations	Approximately 514 liters per minute (up to 2800 liters per minute)	Mostly ferrous iron (1 to 21 mg/L)	2 to 310 mg/L
Mixture of Surface Overflow and AMD Siphoned From Pond 1	May 9 to July 4 (58 Days)	AMD was high in acidity and high in metals concentrations	Approximately 125 liters per minute	Mostly ferrous iron (21 to 910 mg/L)	310 to 490 mg/L
AMS Siphoned From Pond 1	July 5 to July 10 (5 Days)	AMD was high in acidity and high in metals concentrations	Approximately 315 liters per minute (up to 1250 liters per minute)	Mostly ferric iron (up to 1000 mg/L)	Up to 490 mg/L

2.2 Treatment overview

The treatment system consisted of an RCTS-30HS (rotating cylinder treatment system-thirty inch diameter rotor high speed) unit, two to three 1900 liter lime slurry tanks, a lime delivery pump, a 7.5 centimeters siphon line from pond 1 and various pumps to bring AMD to the system from the upper ponds and Pond 3. Trash pumps (7.5 cm.) and 7.5 cm. siphon lines were used to discharge AMD from pond 3 to Leviathan Creek via the existing overflow infrastructure.

2.2.1 RCTS-HS System

Acid mine drainage typically contains sulfuric acid along with elevated concentrations of dissolved ferrous iron and other metals. The oxidation of ferrous iron to ferric iron is a commonly used process in most lime treatment systems because ferric iron is precipitated from solution at a lower pH than ferrous iron. Treating AMD at a lower pH allows for treatment of iron and aluminum in a single stage. This oxidation is typically accomplished by pumping air with compressors and mixing the air, lime and AMD with agitation mixers in large tanks. Although this method of treatment is effective, it requires significant power and a large amount of space to house the reaction tanks. The patented Rotating Cylinder Treatment System (*RCTS*^{TM}) utilizes shallow trough-like cells or cylinders (that contain the AMD being treated) and rotating cylinders within these cells to transfer oxygen and agitate the AMD. This system has been tested on multiple sites in Nevada , Idaho and California. When compared with conventional systems it requires less power (<1800 watts) and less space and is more efficient at mixing lime (near 100% efficiency). Figure 1 displays the RCTS-HS system utilized for the Pond 3 Emergency Treatment in 2006.

Figure 1 2006 RCTS-HS Treatment System

2.2.2 Treatment Concept

The treatment concept in 2006 was to treat the AMD in pond 3 and any AMD that could potentially overflow to Leviathan Creek from the upper ponds. Initially, AMD was pumped from Pond 3 (near the influent point of the overflow from the upper ponds), to the RCTS-HS where lime was added to the AMD, the dissolved ferrous iron was oxidized, and metals and sulfate were precipitated. The treated water and precipitated solids were then either gravity fed back to the pond or pumped and mixed back into the pond at strategic locations. During the initial hours of treatment, overflow from Pond 3 to Leviathan Creek occurred at a pH less than 7 s.u.. Once the pH at the discharge end of the Pond 3 surpassed 7 s.u,, active discharge began with the use of pumps and siphon hoses. By actively discharging at a higher rate than the inflow, Pond 3 was drawn down, creating freeboard. This allowed the AMD to be treated and contained in Pond 3 until the water was suitable for a controlled discharge. Figures 2 and 3 display the discharge pumping setup. On April 25 a siphon line was installed to gravity feed AMD from Pond 1 directly into the *RCTS*™ Treatment System. By doing this, the level in the upper ponds was drawn down which reduced the amount of AMD that overflowed from the upper ponds to Pond 3. By June 4, overflow had decreased to less than 3 gallons per minute.

Figure 2 Water discharge from Pond 3 to the Leviathan Creek.

Figure 3 Suction lines located near surface to avoid discharge of sediments.

2.3 AMD treatment

Acid mine drainage composed of mainly rain and snow-melt began to overflow from the surface of Pond 3 to Leviathan Creek sometime on April 12, 2006, due to heavy spring rain and snow. AMD treatment began on April 14, and was operated continuously through April 16. The system was shut down for approximately 33 hours between April 16 and 19. The system was restarted on April 19 and operated continuously until July 10. Overall the treatment system was operated for 85 days. During this time approximately 28 million liters of AMD was treated and discharged by actively pumping or siphoning. There was also an indefinite volume of treated water and partially treated AMD that overflowed to the creek on April 14, 15 and 18.The process of adding lime had begun on this partially treated AMD and most of the metals had precipitated from solution, however, it had not yet reached the target pH range for discharge.

2.3.1 Initial AMD (low acidity, ferrous iron AMD)

The treatment rate in the "Spring Emergency Treatment 2006" varied with changing AMD chemistry and conditions. The AMD that was initially contained in Pond 3 was untreated low acidity AMD that consisted mainly of snow and ice melt. In addition, the upper ponds were partially stratified initially and the surface of the ponds which drained into Pond 3 was also characterized with a low acidity. AMD was pumped from Pond 3 (near the upper pond's overflow discharge point into Pond 3) and lime was added to the AMD and mixed via the *RCTS*^{TM} unit. The high pH discharge from the *RCTS*^{TM} unit was then mixed into Pond 3. By treating the pond in this manner we were able to treat the initial approximately 3.7 million liters at high rate. Lime addition began at 11:30 a.m. on April 14. The initial pH of Pond 3, measured at numerous points around the pond, was approximately 3.8 with an acidity of 134 mg/L $Ca(OH)_2$. By 10 a.m. on April 15, the average pH of Pond 3 was 8.31. During this time, the *RCTS*^{TM} effluent was added to Pond 3 at a pH value to adjust the entire pond to above 8 s.u.. This translates to an AMD treatment rate of approximately 2800 liters of AMD treated per minute. However, the pond was not thoroughly mixed. At the sampling point near the discharge the pH was approximately 6.5. At approximately 8 a.m. on April 16, the pH near the discharge point was approximately 8.6. Once the pond pH near the discharge point was adequate, the AMD began to be actively discharged by pumping or siphoning out of Pond 3 and directing the discharge through the overflow structure to Leviathan Creek. By actively discharging at a higher rate than the inflow, pond 3 could be drawn down below the overflow elevation, creating freeboard. This allowed the AMD to be treated and contained in Pond 3 until the water was suitable for a controlled discharge. On April 25 a siphon line was installed to gravity feed AMD from Pond 1 directly into the *RCTS*^{TM} Treatment System. The acidity of the initial AMD from the surface of Pond 3 was 92 mg/L. The overflow acidity from the upper ponds was initially 41 mg/L and by April 26 the acidity increased to 136 mg/L.

2.3.2 Mixed AMD Treatment (high acidity, ferrous iron AMD)

The initial AMD contained in Pond 3 and the overflow from the upper ponds consisted of mainly ice and snow melt with a small amount of acid mine drainage mixed in. By April 30, the mixing of the stratified layers in the upper ponds was sufficient to increase the acidity of the overflow to 404 mg/L. In addition, on April 25 a siphon was placed in Pond 1 to draw AMD from Pond 1directly to the *RCTS*^{TM} treatment system. The intake from this siphon line was placed 3 meters from the edge of Pond 1 and approximately 0.5 meters from the surface. The acidity from this siphon line was 437 mg/L initially. By May 8, the acidity increased to 1800 mg/L and by June 29, the acidity had reached 5207 mg/L. The AMD during this period was high in acidity and also high in ferrous iron. Initially, greater than 90% of the iron was in the ferrous state. During this period, the rate that the AMD could be treated was controlled by the amount of oxidation that could be achieved within the system.

2.3.3 Mixed Oxidized AMD Treatment (high acidity, ferric iron AMD)

By July 4 the majority of the iron had oxidized within the upper ponds and the ponds were well mixed. The AMD that was treated after July 4 was high in acidity and contained iron mainly in the ferric state. On July 6 the acidity was measured at 5346 mg/L. During this period of treatment, virtually all of the AMD that was treated came from the siphon line. Because the majority of the iron was in the ferric state, the AMD could be treated at a high rate during this period. The limitation of the rate of treatment during this period was the rate at which lime could be added. Because the acidity was high, the flow that could be treated continuously was limited to approximately 750 lpm with the lime pump that was being used.

2.4 Sampling summary

Pond 3 monitoring was conducted multiple times per day on most treatment days. Pond 3 monitoring stations are displayed in Figure 4.

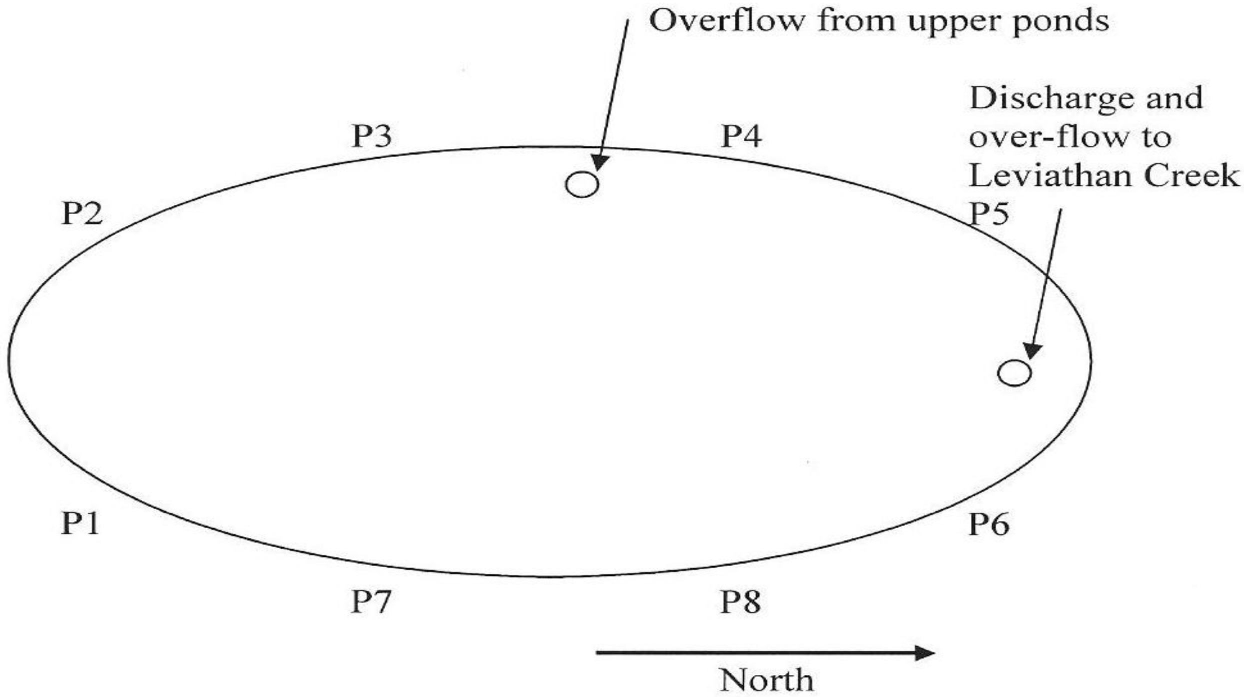

Figure 4 **Pond 3 monitoring stations**

TKT field monitoring included the determination of flow, pH, oxidation-reduction potential (ORP), conductivity, dissolved oxygen (DO), and temperature. Discharge flow rates were estimated from pump and pipe manufacturer's specs. All other field measurements were measured with a Yellow Springs Instrument (YSI) 556-field meter, calibrated before each visit. Certified laboratory samples were taken by the Water Board staff at least once on discharge days following protocols defined in the Water Board's "Sampling and Analysis Plan for Surface Water Monitoring" (January 2004) and were sent to Weck Laboratories in Industry, CA for analysis. Grab samples were collected from near the discharge point in Pond 3 and the pH was monitored continuously on discharge days. Sampling stations were as follows: Pond 1, Pond 2 S, and Pond 3.

Results

The directives from the Environmental Protection Agency were to prevent untreated acid mine drainage from the upper ponds from overflowing to Leviathan Creek. Because this was an emergency effort and overflow appeared to be imminent, the directives were to neutralize the AMD to a pH between 7 and 9 s.u. prior to overflow or discharge to Leviathan Creek. Despite intensive efforts to mobilize in time to treat the water prior to overflow, an untreated overflow event did occur between some time on April 12 and approximately 11:30 a.m. on April 14. Although the pH of this water was low (between 3.2 and 3.6), the water was composed mainly of ice and snowmelt and was characterized with low acidity and low metals concentrations.

Treatment began on April 14, while uncontrolled overflow of treated or partially treated water continued between April 14 and April 20. On April 14, following treatment, the pH at the discharge point varied between 4.5 and 4.9. On April 15 the pH varied between 6.4 and 7.7. On April 16 the pH varied between 8.6 and 9.0. On April 16 Pond 3 was actively pumped down and discharged to Leviathan Creek and the system was shut down. On April 18, heavy precipitation unexpectedly caused Pond 3 to overflow and the pH was measured at 4.6. On April 18 at approximately 11:30 p.m. the system was started back up and by 11:30 a.m.

on April 19 the pH was back up to 9.0. The pH on April 19 varied from 5.6 to 9.0. By April 20 the uncontrolled overflow was stopped by actively pumping treated water through the overflow structure to Leviathan Creek. The pH varied between 6.2 and 9.0 on April 20. Following April 20, all water was discharged actively at a pH between 7 and 9 with a target pH between 8.0 and 8.5. Table 2 displays the field data.

Date	Station	pH Water Board	pH average TKT	Temp. (^oC)	EC (uS)	SC (uS)	Date	Station	pH Water Board	pH average TKT	Temp. (^oC)	EC (uS)	SC (uS)
4/11/06	Pond 3	3.8		2.5	91	160	4/30/06	Pond 3	7.4	7.57	17	776	916
4/11/06	Pond 3 Dup	3.8		2.5	91	160	5/1/06	Pond 3	8.9	7.92	12.9	618	805
4/11/06	Pond 2 S	2.9		3.6	123.4	210.2	5/5/06	Pond 3	7.7	7.65	11.5	866	1166
4/13/06	Pond 3	3.6		3.5	313	531	5/5/06	Dup	7.7		11.5	866	1166
4/13/06	Pond 2 S	3.1		1.8	106	NA	5/8/06	Pond 3	8.4	8.05	16.4	1235	1476
4/14/06	Pond 3	4.2	4.57	5.2	709	1142	5/11/06	Pond 3	8.2	8.16	14.7	1440	1794
4/15/06	Pond 3	5.9	6.68	3.6	720	1218	5/15/06	Pond 3	8.5	8.27	15.9	1887	2284
4/16/06	Pond 3	7.6	8.82	1	663	NA	5/15/06	Pond 1	2.6	2.8	18	3724	4297
4/18/06	Pond 3	4.6		3.8	679	1141	5/18/06	Pond 3	8.5	8.03	17.3	2222	2605
4/19/06	Pond 3	8.9	7.77	6.3	723	1126	5/18/06	Pond 1	2.4	2.8	20.3	4091	4493
4/19/06	Dup	8.9		6.3	723	1126	5/22/06	Pond 3	7.8	8.47	12.9	2078	2704
4/20/06	Pond 3	5	7.77	9.3	787	1125	5/26/06	Pond 3	8.4	8.14	15.6	2607	3170
4/21/06	Pond 3	9.9	9.11	7.5	721	1083	6/2/06	Pond 3	8.7	8.49	16.1	3230	3892
4/22/06	Pond 3	8.2	8.11	9.1	703	99.7	6/2/06	Pond 1	2.3	2.75	19	5320	6020
4/24/06	Pond 3	7.8	7.88	8.6	526	767	6/12/06	Pond 3	8.5	8.4	19	3494	4228
4/27/06	Pond 3	7.5	8.32	12.7	554	722	7/3/06	Pond 1	2.7	2.6			
4/28/06	Pond 1	2.9		13.5	560	715	7/3/06	Pond 3	8.2	8.21			
4/28/06	Pond 3	9	8.3	12.7	566	740	7/10/06	Pond 3	7	8.30			
4/29/06	Pond 3	7.1	7.5	11.6	544	731							

Table 2. AMD Treatment Field Data from Water Board (light grey untreated) (dark grey partially treated)

Although only required to meet pH objectives between 7 and 9, the RCTS-HS treatment system was effective at removing metals to below the discharge objectives set forth in the Removal Action Memorandum (RAM) (See Table 3).

Target Metals	Maximum (a) (µg/L)	Average (b) (µg/L)	Target Metals	Maximum (a) (µg/L)	Average (b) (µg/L)
Primary target metals			Secondary water quality indicator metals		
Aluminum	4000	2000	Cadmium	9	4
Arsenic	340	150	Chromium	970	310
Copper	26	16	Lead	136	5
Iron	2000	1000	Selenium	No standard	5
Nickel	840	94	Zinc	210	210
(a) Based on a daily composite of three grab samples (b) Based on the average of four consecutive daily composite samples					

Table 3 Removal Action Memorandum Discharge Criteria

Once treatment began during the 2006 Spring Treatment, the maximum daily RAM discharge objectives were not exceeded, with the exception of iron which slightly exceeded the objective once. Aluminum, iron and copper exceeded the RAM discharge objectives prior to treatment. Copper and aluminum exceeded discharge objective on April 14 just following the initiation of treatment. Selenium (which is not removed effectively by lime precipitation without the presence of high concentrations of other metals which co-precipitate) exceeded the four day average RAM objective between April 14 and April 22. Figures 5, 6 and 7 graphically display the data over time for Aluminum, Iron and Copper. Water was treated 24 hours per day, 7 days per week from April 19 to July 7. The controlled discharges occurred when the capacity of Pond 3 was near full and the pH of Pond 3 near the discharge point was between 7 and 9. A target discharge pH of 8.0 to 8.5 s.u. was set, however the Pond 3 pH sometimes varied and in a few circumstances the discharge was stopped do to the pH approaching 7 or 9 s.u. Samples were taken during discharge whenever practical however on April 27 and April 28 the samples were taken after the discharge had been stopped and on May 5 the samples were taken prior to discharge.

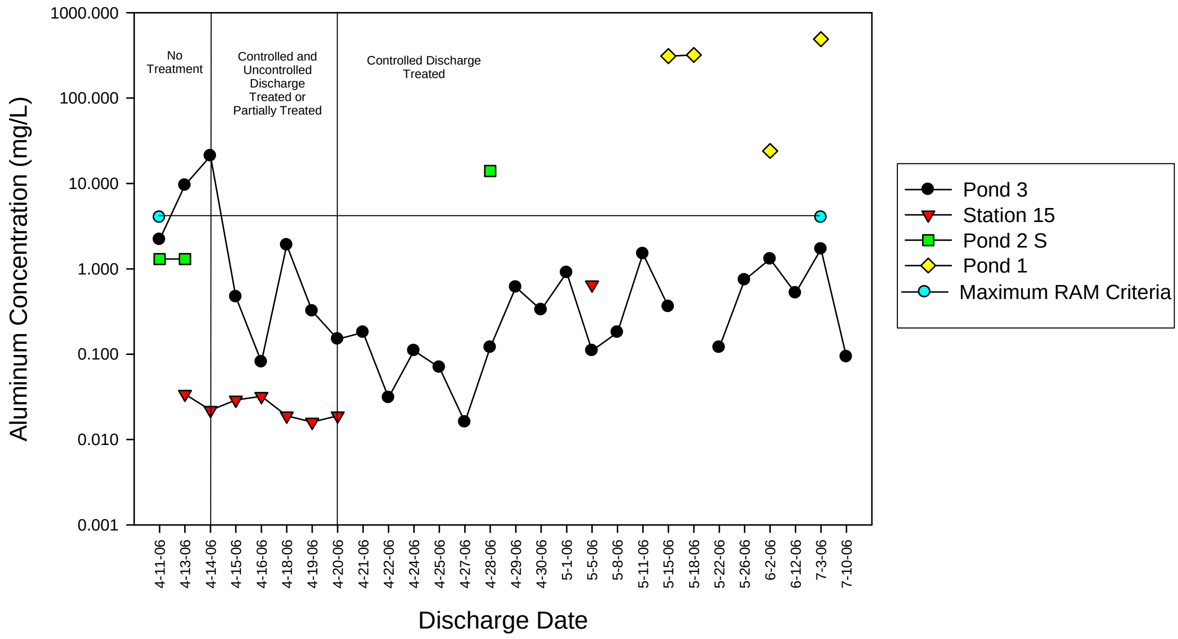

Figure 5 Leviathan pond 3 Aluminum concentrations

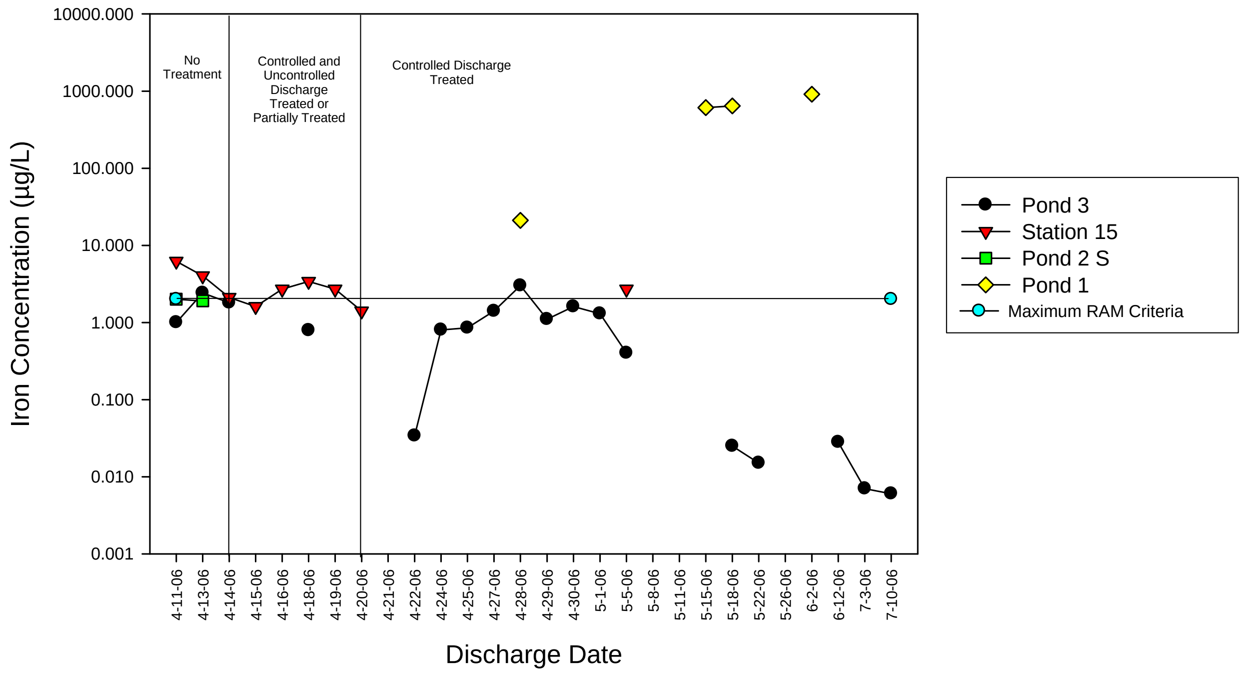

Figure 6 Leviathan pond 3 Iron concentrations

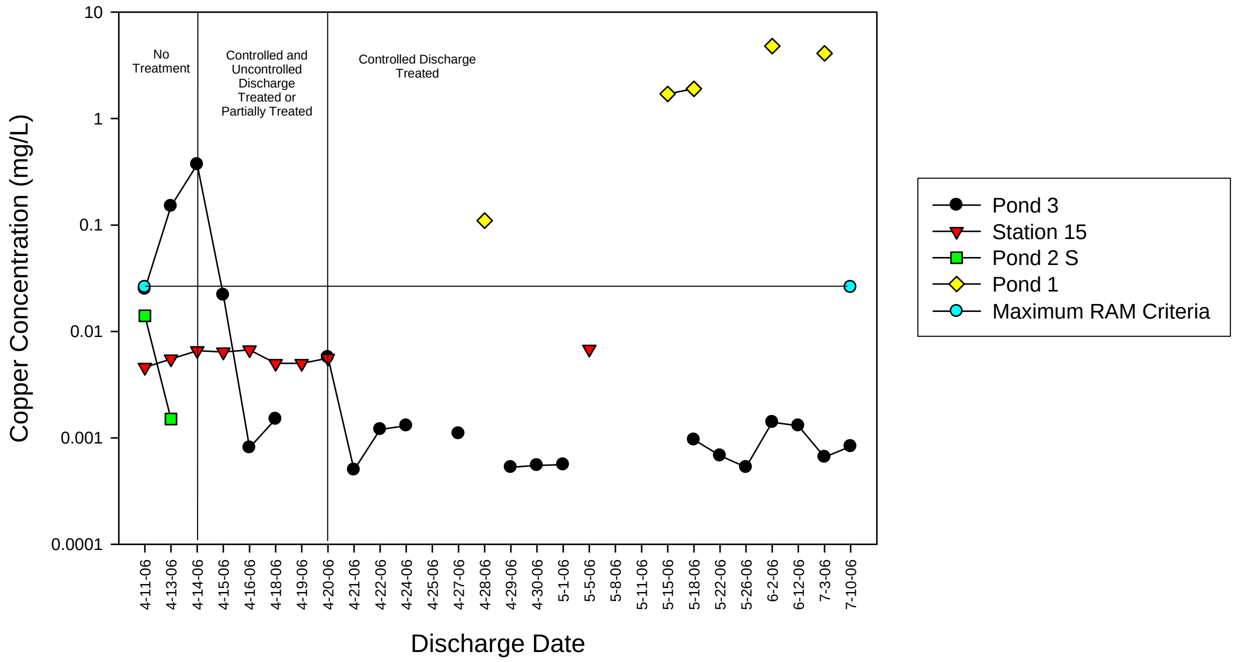

Figure 7 Leviathan pond 3 Copper concentrations

3. Conclusions

The *RCTS*^{TM}-HS mobile unit was mobilized quickly and under harsh conditions. The treatment system was effective at discharging water between pH 7 and 9 s.u. and only one sample exceeded the Maximum RAM discharge criteria once all discharges were controlled. In 2006 approximately 28 million L of AMD was treated compared to approximately 2.27 million L in 2005. Forty two and one half tons of dry lime was consumed. Although not quantified on this project, the *RCTS*^{TM} system is usually near 100% efficient at dissolving lime for alkalinity generation. The system operated on less than 1600 watts of electricity and was placed on a footprint of approximately 3m x 10m. On average, a two man crew was on site 4.6 hours per day, which included time on site during discharge, which had to be continuously monitored. The RCTS-HS treatment system not only controlled the pH of the discharged water, it was also effective in the removal of metals in a cost effective, energy efficient manner.