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FINAL REPORT—PERMEABLE TREATMENT WALL EFFECTIVENESS MONITORING, NEVADA STEWART MINE SITE

MINE WASTE TECHNOLOGY PROGRAM ACTIVITY III, PROJECT 39

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Mine Waste Technology Program

Permeable Treatment Wall Effectiveness Monitoring Project Nevada Stewart Mine

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Foreword

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Sally Gutierrez, Director
National Risk Management Research Laboratory

Abstract

This report summarizes the results of Mine Waste Technology Program (MWTP) Activity III, Project 39, *Permeable Treatment Wall Effectiveness Monitoring Project*, implemented and funded by the U.S. Environmental Protection Agency (EPA) and jointly administered by EPA and the U.S. Department of Energy (DOE). This project addressed EPA's technical issue of Mobile Toxic Constituents – Water through a field demonstration of a water treatment process based on the use of Apatite II™ treatment medium at a remote, inactive underground mine.

This project was undertaken to demonstrate the effectiveness of Apatite II™ (cleaned fishbone) to treat metal-laden water flowing from an abandoned mine. The Nevada Stewart Mine (NSM), located in the Coeur d'Alene Basin near Pinehurst, Idaho, was selected as the site for the field demonstration. The NSM is part of the Bunker Hill Mining and Metallurgical Complex, which was placed on the National Priorities List (NPL) for Superfund cleanup of heavy metals, mainly zinc, lead, and cadmium.

To determine the effectiveness of the apatite material, a permeable treatment wall system [also referred to as the Apatite™ II Treatment System (ATS)] was constructed by MSE Technology Applications, Inc. (MSE) using funds provided by DOE. Subsequently, approximately 17 gallons per minute of the NSM adit discharge was directed through the ATS. The gravity fed ATS was designed and constructed using a baffled, up-flow system that contained a 3:1mixture by volume of apatite and gravel. The composition and quality of the influent and effluent water from the system was monitored by MSE using funding provided by the MWTP on a monthly basis for a 2-year period.

After evaluating the results from the ATS, it was concluded that the system effectively attenuated zinc, iron, manganese, lead, and cadmium as substantiated by the decrease in aqueous phase concentrations between the influent and effluent waters, and increases in those constituents within the solid phase media contained in the system's three treatment tanks. The results from the ATS showed that a combination of mechanisms removed attenuated the metals from the NSM adit discharge. The only removal mechanism verified in the ATS was sulfide mineral precipitation. Other likely or possible removal mechanisms include phosphate mineral precipitation, adsorption, and cation substitution. Results from the microscopy, geochemical modeling, and data evaluation revealed that sulfide mineral precipitation was the main removal mechanism for zinc, forming a zinc sulfide.

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Acronyms and Abbreviations

Ag	silver
Al	aluminum
As	arsenic
ATS	Apatite II™ Treatment System
Au	gold
Be	beryllium
BEIPC	Basin Environmental Improvement Project Commission
Ca	calcium
Cd	cadmium
CdS	cadmium sulfide
CFI	Center for Innovation
CLP	Contract Laboratory Program
Co	cobalt
Cr	chromium
CRDL	contract required detection limit
Cu	copper
DO	dissolved oxygen
DOE	U.S. Department of Energy
DS	downstream
EDX	energy dispersive X-ray
EPA	U.S. Environmental Protection Agency
Fe	iron
FeS	iron sulfide
Golder	Golder Associates Inc.
gpm	gallons per minute
Hg	mercury
IAG	Interagency Agreement
ICP	inductively coupled plasma
ICP-ES	inductively coupled plasma emission spectrometer
IDEQ	Idaho Department of Environmental Quality
IDL	instrument detection limit
K	potassium
lb	pound
lb/mo	pounds per month
LC	lethal concentration
MDL	method detection limit
Mg	magnesium
μg/L	micrograms per liter
mg/L	milligrams per liter
MHRW	moderately hard reconstituted water
mL/min	milliliter/minute
Mn	manganese
MPN	most probable number
MSD	moving standard deviation
MSE	MSE Technology Applications, Inc.

Acronyms and Abbreviations (Cont'd)

mV	millivolt
MWTP	Mine Waste Technology Program
Na	sodium
Ni	nickel
NOAEL	no observed acute effect level
NPV	net present value
NSM	Nevada Stewart Mine
O&M	operating and maintenance
ORP	oxidation-reduction potential
OU3	Operable Unit Three
P	phosphorus
Pb	lead
PbS	lead sulfide
pcf	per cubic foot
ppb	parts per billion
ppm	parts per million
PRB	permeable reactive barrier
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
ROD	record of decision
RPD	relative percent difference
S	sulfur
Sb	antimony
SC	specific conductivity
Se	selenium
SEM	scanning electron microscopy
Si	silicon
SP1	Sample Port 1
SP2	Sample Port 2
SP3	Sample Port 3
SP4	Sample Port 4
SPA	Sample Port A
SRB	sulfate-reducing bacteria
SVNRT	Silver Valley Natural Resource Trust
Ti	titanium
U	uranium
US	upstream
wt%	weight percent
XRD	X-ray diffraction
Zn	zinc
ZnS	zinc sulfide

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Executive Summary

The Mine Waste Technology Program (MWTP) Activity III, Project 39, *Permeable Treatment Wall Effectiveness Monitoring Project* was implemented by the U.S. Environmental Protection Agency (EPA) and jointly administered by EPA and the U.S. Department of Energy (DOE). Project 39 addresses EPA's technical issue of Mobile Toxic Constituents – Water. This project is a collaborative effort between DOE and EPA's MWTP. The DOE-funded portions of the project included the design and construction of the Apatite II™ Treatment System (ATS) and in-line monitoring system. EPA's MWTP activities addressed establishment of the baseline investigation of the project site, long-term performance monitoring, and decommissioning/closure of the ATS.

The project was conducted at the Nevada Stewart Mine (NSM) site located within the Coeur d'Alene Mining District in Idaho. The NSM is an abandoned lead-zinc mine with an adit discharge of approximately 50 gallons per minute (gpm), primarily contaminated with lead, zinc, and manganese, which drains directly into Highland Creek. The ATS was designed to treat approximately 20 gpm (40%) of the NSM adit discharge. The adit discharge was captured upon exiting the adit and gravity fed through the ATS. Primarily, the ATS consisted of three treatment tanks (labeled 2, 3, and 4) filled with reactive media, which consisted of a 2:1 mixture by weight of gravel to cleaned fishbone (Apatite II™). Monthly performance monitoring of the ATS was conducted between November 2002 and August 2004. Both the treatment system influent and effluent were monitored, as well as upstream and downstream locations relative to the ATS on Highland Creek. For the duration of the project, approximately 13.5 million gallons of water were treated by the ATS.

The project was performed to determine the effectiveness of the ATS in reducing the concentrations of dissolved metals in the mine discharge and to define the attenuation mechanisms (i.e., physical and/or chemical) that reduced the total metal loading of treated waters. To determine the effectiveness of the ATS at reducing the metals loading, the percent reduction was calculated for each metal listed as a target constituent for the duration of the project. The main target constituents present in the NSM discharge included zinc, iron, manganese, calcium, magnesium, lead, and cadmium. Results indicate that the ATS effectively attenuated cadmium, lead, zinc, iron, and manganese, as evidenced by the decrease in aqueous concentrations between inflow and outflow and the increase in solid phase concentrations of these constituents. For the total ATS, the average percent reduction for dissolved zinc, cadmium, iron, and manganese was 55%, 85%, 73%, and 53%, respectively. Dissolution of calcium and magnesium and corresponding increases in concentrations of these constituents occurred over the duration of the project.

Each of the three reactors within the ATS exhibited strong variability in treatment efficiency throughout the project duration, which was dependent upon flow rate, retention time, surface contact, permeability through the medium, and chemistry of the water. Tank 4 treated the water the most effectively, and the average percent reduction of dissolved zinc, cadmium, iron, and manganese for Tank 4 was 94%, 89%, 74%, and 66%, respectively. Tank 4 treated the lowest flow, provided the longest retention time, and had the most reducing environment inside the tank. The increases in concentration of calcium and magnesium were also the greatest for this tank.

A second method of calculating the efficiency of the ATS was to determine the reduction in metals loading entering Highland Creek during the project period. The average monthly zinc loading, for example, was reduced from 37 pounds per month (lb/mo) prior to treatment to 21 lb/mo after ATS installation.

Extensive research activities were conducted during this project to identify the metals removal mechanisms within the ATS. The attenuation mechanisms identified included precipitation, adsorption, and cation substitution. Specific metals within the influent water were attenuated in different manners. Both the geochemical modeling by Golder Associates, Inc., and mineralogical analysis by Montana Tech confirmed that sulfide precipitation of zinc was probably the dominant mechanism for zinc attenuation within the treatment tanks. This process resulted from reducing conditions being created through the consumption of organic portions of the substrate and the accompanying reduction of sulfate to produce insoluble sulfide by sulfate-reducing bacteria. Attenuation of cadmium and lead due to precipitation was inconclusive; however, speciation modeling showed supersaturation with respect to both cadmium and lead sulfide. The relatively low solid phase concentrations of these metals in the treatment tanks prevented identification of any cadmium/lead secondary mineral phases.

Speciation modeling identified the production of manganese phosphate as a potential precipitate formed within the ATS. This indicates but does not definitely verify that phosphate mineral precipitation was the potential attenuation mechanism controlling manganese concentrations. Similarly, formation of strengite (Fe-phosphate) was identified as a possible sink for iron. Effluent saturation indices indicate undersaturation with respect to hydroxypyromorphite. Because the influent lead concentrations were very low, substitution of lead for calcium during reprecipitation of hydroxyapatite may be one mechanism responsible for lead attenuation. Adsorption of lead, cadmium, and manganese onto ferrihydrite or the Apatite II^{TM} treatment medium could account for an additional reduction in concentration of these metals.

Water samples from the NSM site in Idaho were shipped to the EPA Laboratory in Cincinnati, Ohio, for toxicity tests. A series of acute aquatic toxicity tests with *P. promelas*, the fathead minnow, and *C. dubia*, a freshwater invertebrate, were conducted with these samples. The purpose of these tests was to establish the level of toxicity for discharge from the mine site and to evaluate the effectiveness of the treatment process currently being used at this site. The results from the tests indicate that the treatment system being used to remediate the waste from this mine site reduced the toxicity of the effluent water over that of the influent water.

After assessing the results from the NSM project, it was determined that metals removal was equivalent to about 5% of the weight of the apatite used. For future utilization of apatite for removal of metals, the treatment tank design should be modified to improve the effectiveness and longevity of an ATS by maximizing residence time, preventing plugging, and including means for permeability enhancement/media replacement strategies.

1. Introduction

1.1 Project Description

Mine Waste Technology Program (MWTP) Activity III, Project 39, *Permeable Treatment Wall Effectiveness Monitoring Project* was funded by the U.S. Environmental Protection Agency (EPA) and jointly administered by EPA and the U.S. Department of Energy (DOE) through an Interagency Agreement (IAG). MSE Technology Applications, Inc. (MSE) implements the MWTP for EPA and DOE. For this project, MSE monitored and evaluated a fishbone, Apatite II^{TM} Treatment System (ATS) designed and implemented to reduce the metals loading from an adit discharge water. The reactive media in the treatment cells consisted of a mixture of fishbone (Apatite II^{TM}) and gravel. The objective of Activity III, Project 39 was to monitor and determine the effectiveness of the fishbone apatite material at reducing metals loading in the discharge flowing from an abandoned mine and determine the metal attenuation mechanisms.

The Nevada Stewart Mine (NSM) site selected for this demonstration project is located in the Coeur d'Alene Mining District approximately 6 miles south of Pinehurst, Idaho. The NSM is an abandoned lead (Pb)-zinc (Zn) mine discharging an estimated 50 gallons per minute (gpm) from the collapsed mine adit and underground workings. The primary contaminants in the NSM adit discharge are cadmium (Cd), Pb, iron (Fe), manganese (Mn), and Zn. However, the characterization data indicated that Pb and Cd concentrations were very low during this project, near laboratory detection limits.

The two major phases of the *Permeable Treatment Wall Effectiveness Monitoring Project* were: 1) implementation of the ATS; and 2) long-term monitoring of the ATS. Construction of the ATS was funded by DOE in September 2002 and implementation of long-term monitoring, testing, and evaluation of the ATS system was funded by EPA's MWTP for a 2-year period.

This final report contains the following information:

- Section 1—Description of the demonstration site, scope of work, criteria for success, project schedule, and history of demonstration activities.
- Section 2—Description of DOE's ATS installation, an overview of how Apatite II™ works, the general approach used for installation of the ATS, project design and assumptions, and implementation of the technology.
- Section 3—Description of the 2-year monitoring and testing program implemented under EPA's MWTP that was used to acquire data for evaluation of the ATS.
- Section 4—Review and interpretation of the results for each stage of the project.
- Section 5—Statistical analysis and evaluation of the 2-year monitoring results.
- Section 6—Cost analysis of the ATS on a per-gallon-treated basis.
- Section 7—Summary of quality assurance including activities evaluation and validation of field and laboratory data to determine if the project objectives were achieved.
- Section 8—Project conclusions and recommendations for future projects of this type.
- Section 9—List of references.
- Appendices—Additional data and results.

1.2 Project Objectives and Scope of Work

The overall objective of the monitoring program for the ATS demonstration was to evaluate the ability and efficiency of the system to reduce metals loading of a mining-impacted water. The NSM adit discharge was continuously monitored before and after the ATS was installed to determine if the water quality improved and to determine the attenuation mechanisms (i.e., chemical, biological, or physical) that effectively reduced the metals concentrations.

1.2.1 Technology Criteria

The project objectives to determine the effectiveness of the ATS were defined in the MWTP, Activity III, Project 39, Quality Assurance Project Plan (QAPP) (Ref. 1). The effectiveness of the technology was determined by calculating the percent reduction of dissolved metals loading in the treated water compared to the influent water. The system was monitored for a 2-year period. This allowed the ATS system to be fully evaluated, even during low metal removal periods to determine if the metal removal varied seasonally or with permeability enhancements.

1.3 Historic and Background Information

This section provides pertinent information regarding the NSM site selection, as well as the selection of fishbone apatite (hydroxyapatite) as a metals removal medium. The background information is presented as:

- the history of the NSM site and surrounding area;
- regulatory history of the local area;
- previous projects using the Apatite II™ medium for remediation purposes; and
- basic metals removal mechanisms when using Apatite II™ (hydroxyapatite).

1.3.1 NSM Site History

Water from the Coeur d’Alene Mining District, which produced over 150 million tons of Pb, Zn, and silver (Ag) ore since 1885, flows into the South Fork of the Coeur d’Alene River. The South Fork of the Coeur d’Alene River water contains high dissolved metal concentrations that severely inhibit the survival of fish, other aquatic biota, and wildlife along much of the 30-kilometer reach draining the district (Ref. 2). Zinc accounts for approximately 97% of the dissolved heavy metal load, followed by Pb and Cd (approximately 1% each), with other metals [copper (Cu), nickel (Ni), cobalt, antimony (Sb), gold, mercury (Hg)] totaling less than 1% (Ref. 2).

The NSM site is located in Shoshone County near the headwaters of Highland Creek approximately 2 miles east of its confluence with the East Fork of Pine Creek (Figure 1-1). The East Fork of Pine Creek flows into the South Fork of the Coeur d’Alene River. The NSM is an abandoned Pb-Zn mine located 6 miles south of Pinehurst, Idaho, in the Coeur d’Alene Mining District. The waste forms on the site consisted of a discharging adit and surface waste piles. Approximately 8,100 cubic yards of floodplain deposited mine wastes were removed from the site to the Central Impoundment Area at the nearby Bunker Hill Site. The streamside wasterock dump piles at the site were recently pulled back from the stream and recontoured to prevent erosion and reduce contaminant loading to Highland Creek. Discharge from the NSM adit drains directly into Highland Creek (Figure 1-2) and has continuous flow of approximately 50 gpm (Ref. 3).

Most receiving waters in the local vicinity of the NSM have recorded pH values close to neutral and low metals and suspended solids concentrations. However, waters discharging from the NSM carry an increased amount of metals that are detrimental to the adjacent receiving stream. Analytical results indicate high levels of dissolved Zn, Fe, and Mn in the NSM adit drainage and high levels of Zn and Fe in the soils. The concentrations for Cd and Pb in the adit drainage were near the laboratory detection limits.

1.3.1.1 Geology

Coeur d’Alene Basin and mining district geology within the Coeur d’Alene Basin is Precambrian Belt Supergroup rocks consisting of quartzite, carbonates, fine-grained argillites, and dolomitic rock (Ref. 4). The Precambrian rocks were deformed and intruded. Deformations and intrusions and resulting mineralization have formed deposits of valuable minerals including sulfides of Pb, Ag, Zn, Sb, Cu, cobalt (Co), and traces of gold (Au) (Ref. 4). The mineralogy of the mines is dominated by sphalerite [zinc sulfide (ZnS)] that was predominately associated with galena [lead sulfide (PbS)]. Cadmium was a trace element predominantly found with the sphalerite and produced as a by-product of the smelting process.

1.3.1.2 Physiography

Terrain around and in the vicinity of the NSM is steep and slightly wooded with various vegetation/grasses. Narrow, steep, and unpaved roads provide vehicle access to most areas of the mine surface. Winter access to the site can be difficult due to deep snow and steep terrain, which impedes sampling efforts (Figure 1-3). During the winter months, however, the NSM discharge did not freeze, nor did the flow through the apatite treatment system.

1.3.2 Site Location History

In 1983, the Bunker Hill Mining and Metallurgical Complex, a former mining and smelting area, located within the South Fork of the Coeur d'Alene River drainage basin, was placed on the National Priorities List for Superfund cleanup due to the presence of high levels of Zn, Pb, Cd, arsenic (As), and other heavy metals. The Bunker Hill Mining and Metallurgical Complex was divided into three distinct areas: Operable Unit One (populated areas); Operable Unit Two (nonpopulated areas of the complex); and Operable Unit Three (OU3) (any mining-related contamination on the broader Coeur d'Alene Basin).

The NSM site is located within OU3. In September 2002, the record of decision (ROD) for OU3 was signed and identified the selected remedy for the area. The Basin Environmental Improvement Project Commission (BEIPC) was created to implement the EPA ROD for OU3. Within OU3, the BEIPC identified four areas that represented the greatest risk, either due to potential human exposure or high levels of contamination. The upper and lower regions of Pine Creek were identified as one of those areas. The NSM discharge contributes to the contamination within the upper reaches of Pine Creek, and since it is adjacent to the Highland Creek Road, it is easily accessed allowing high exposure to humans.

The overall remedy includes remedial action for:

- protection of human health in the communities and residential areas, including recreational areas of the basin upstream of Coeur d'Alene Lake (the Upper Basin and Lower Basin);
- protection of the environment in the Upper Basin and Lower Basin; and
- protection of human health and the environment in areas of the Spokane River (Ref. 5).

The remedial actions selected in the ROD were not intended to fully address contamination within the Coeur d'Alene Basin (Ref. 5). Thus, achieving certain water quality standards, such as state and federal water quality standards and maximum contaminant levels for drinking water, were out of the scope of the ROD.

1.3.3 Previous DOE Apatite Studies

This project was a leveraged effort between DOE and EPA MWTP. The National Energy Technology Laboratory administered the DOE funding for this project to MSE through Technical Task Plan FT10WE31, Task B – Technology Transfer and Commercialization. The DOE-funded portion of the project covered the design and construction of the treatment barrier and monitoring system. The MWTP portion of the project addressed the baseline investigation of the project site, long-term performance monitoring according to an EPA-approved QAPP, corrective maintenance procedures, decommissioning of the treatment barrier, and data analysis and reporting.

Prior to implementing this project, DOE funded a groundwater treatability study using Apatite II™ as a passive treatment medium for removing soluble uranium (U), other metals, and radionuclides from contaminated groundwater. A pilot-scale reactor was installed to treat U and Cd contaminated groundwater at the Y-12 Plant, S-3 Ponds at Oak Ridge, Tennessee. The pilot-scale system demonstrated that Apatite II™ could

effectively remove the Cd and U under field conditions (99% removal efficiency) (Ref. 6).
In conjunction with the pilot study, several column studies were performed by DOE under a separate project to determine if Apatite II™ could successfully remove ionized metal contaminants from groundwater in the laboratory. These successful Apatite II™ column studies resulted in the initiation of the MWTP project conducted at NSM.

Additionally, an apatite treatment system installed at the Success Mine in Idaho was showing promise for mine discharge treatment.

1.3.4 Background Information on the Application of Apatite™ II

Apatite II™ works to sequester metals by four nonmutually exclusive processes depending upon the metal, the concentration of the metal, and the aqueous chemistry of the system. In the first process, the dissolution of Apatite II™ continuously supplies a small, but sufficient amount of phosphate to solution to exceed the solubility limits of various metal-phosphate phases such as pyromorphite and autunite (Ref. 7). The following reaction illustrates the overall removal process for Pb.

$$Ca_{10}(PO_4)_6(CO_3)_x(OH)_{2-2x} + 10Pb^{2+} + xH^+ + 2x(OH)^- \rightarrow Pb_{10}(PO_4)_6(OH)_2 + xHCO_3^- + 10Ca^{2+}$$

However, under almost all environmental conditions, Pb-pyromorphite and other phosphate based solids will precipitate only in the presence of an apatite seed crystal; as such, these reactions take place on the surface of the apatite (Ref. 8). Without apatite, other Pb-phases will form that have much higher solubilities (Ref. 9). The Apatite II™ grains serve as a source of seed crystal, as well as a source of phosphate (Ref. 10).

The reaction between the apatite and metals is very rapid (Refs. 7, 11, 12, 13, 14, and 15); consequently, the treatment is effective immediately. The macroscopic flow parameters (i.e., grain size, flow rate, and barrier design) are the limiting factors in the field.

The solubility of the original apatite is key to the effectiveness of this mechanism; it must be sufficiently high to be reactive, but sufficiently low to persist in the environment for many years while preventing phosphate loading. In open systems [i.e., permeable reactive barriers (PRBs), soils, or soil columns] the rate of dissolution of the apatite is little affected by the contaminant concentration because the system rarely approaches equilibrium since dissolved constituents are rapidly removed from the system either by flushing or sorption (precipitation or adsorption).

In the second process, Apatite II™ acts as an excellent buffer (buffers to pH 6.5 to 7) for neutralizing acidity through its PO_4^{3-}, OH^-, and substituted CO_3^{2-} groups. Buffering to neutral pH alone is effective at precipitating many metal phases, particularly aluminum (Al) and Fe(+3) (Ref. 16).

The third removal mechanism is surface chemi-adsorption. Apatite II™ is a strong metal adsorbent, particularly of the transition metals, through its uncompensated phosphate and hydroxyl surface groups. Apatite II™ can adsorb up to 5% of its weight by this process (Refs. 12, 7, and 16). For Zn, Cd, and other transition metals, adsorption by apatite is one of the primary mechanisms for removal under most environmental conditions.

The fourth process is biological stimulation. Apatite II™ supplies both phosphate and readily-bioavailable organics at low concentrations for stimulating microbial communities. As an example, in the presence of sulfate and Apatite II™, Zn and Cd can be reduced to sulfides if the other chemical parameters are favorable. This process, along with adsorption, is one of the primary removal mechanisms for these two elements.

The bioavailability of ingested metal bearing apatite is also greatly reduced (Ref. 17), thus, reducing the risk from animal and human ingestion of metals-loaded apatite.

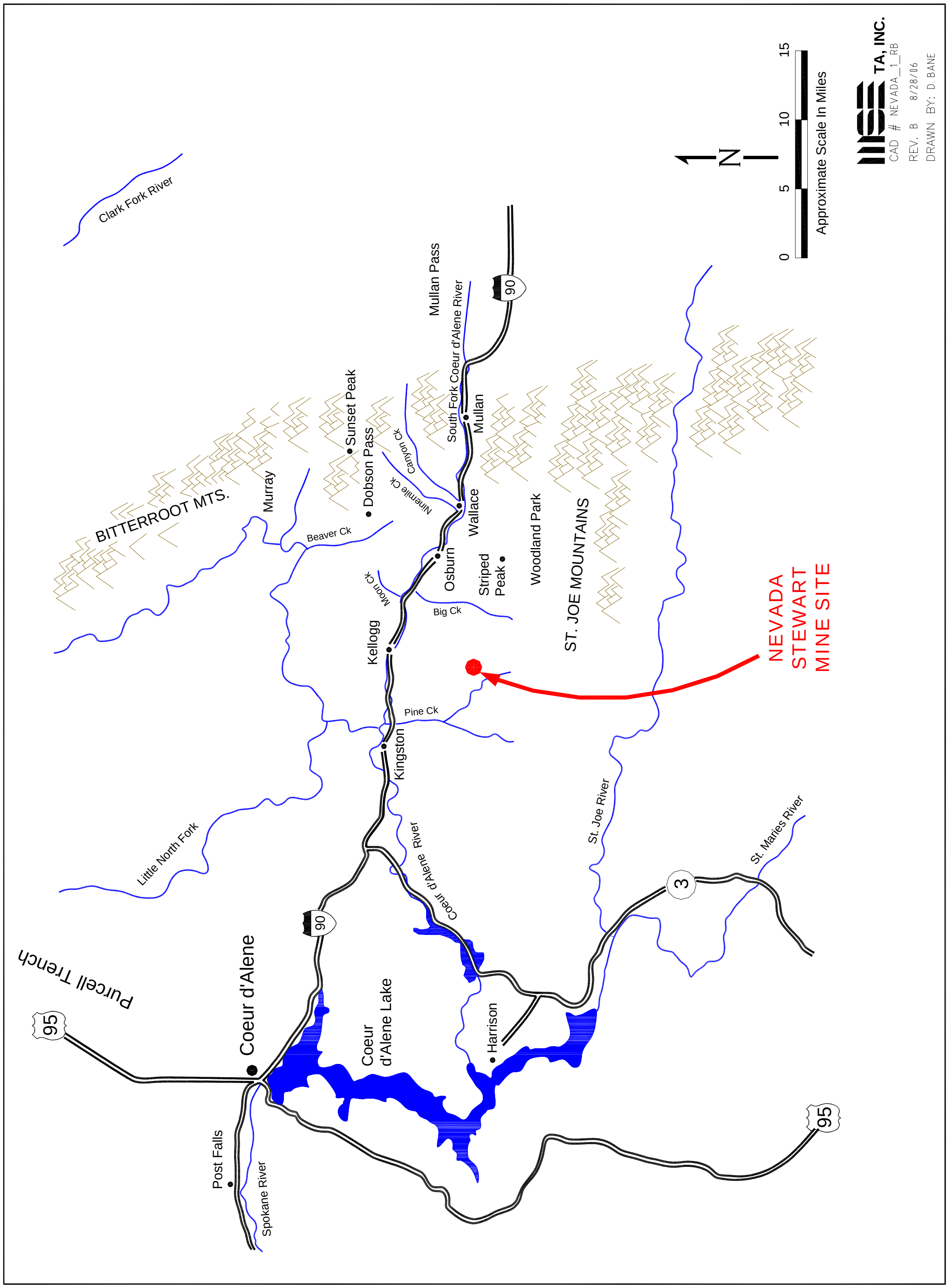


Figure 1-1. Nevada Stewart site map.

Figure 1-2. NSM site prior to technology implementation. Mine discharge shown flowing over road into Highland Creek.

Figure 1-3. NSM site under winter conditions.

2. Apatite^{TM} II Treatment System Installation

2.1 Purpose of Apatite Treatment System Installation

The purpose for the installation of the ATS at the Nevada Stewart Tunnel site was to reduce the concentration of dissolved Zn in the water that flowed through the treatment system; thus, reducing the overall metals concentration in Highland Creek, a tributary of Pine Creek and the South Fork of the Coeur d'Alene River. EPA Region 10, the Idaho Department of Environmental Quality, the Idaho Bureau of Land Management, and MWTP were all involved in the planning and implementation of the project.

A year prior to the installation of the ATS at the NSM, an ongoing demonstration funded by the Silver Valley Natural Resource Trust utilized Apatite^{TM} II material for removing Cd, Pb, and Zn from groundwater being diverted through a PRB located at the Success Mine and Mill site. This demonstration focused on directing contaminated flow through vaults that contained partially saturated apatite medium. Based on the monitoring completed at the Success Mine site between January 2001 and June 2003, the treatment effectively reduced the concentrations of the contaminants in the groundwater passing through the apatite medium by over 90% (Ref. 18).

Several issues arose during the Success demonstration, including odor, phosphorus (P) release, and bacteria release, which were noted as significant for several months after apatite medium emplacement. After one year in place, the odor, P release, and bacteria release from the medium were within acceptable regulatory limits. Because of the proven ability of Apatite II™ to remove metals from lower pH water (Refs. 16, 18, and 19), additional implementation of this technology was needed to test the effectiveness of the medium in treating other waters. The water at the Nevada Stewart Tunnel site was significantly different from the water at the Success site because it had a circumneutral pH and contained higher Fe and calcium (Ca) concentrations.

2.1.1 Project Description

Given the results from the Success Mine project, DOE installed a fully-contained subsurface retention basin and treatment system designed to capture and treat a specified volume of NSM discharge. Prior to the water flowing into the nearby receiving stream, the volume of influent and effluent system flow, and the water quality of those flows were monitored to provide background information and baseline conditions prior to treatment to determine the performance of the treatment system. The project objective was to provide an economical technology that used apatite as a treatment medium to passively remove Zn from the circumneutral water while minimizing odor problems.

2.2 Technology Description

The technology deployed for this project was Apatite II™ (Ref. 20). The treatment medium was placed into a fully-contained subsurface treatment system. Such tank systems, excluding the treatment medium, are typically installed as subsurface stormwater detention/retention basins where surface impoundments are not desirable either because of aesthetics or land value. By placing the treatment medium into a contained subsurface retention system/tank, several advantages over surface treatment systems were recognized, which included:

- significant odor control;
- protection from freezing;
- protection from vandalism and damage from animals;
- ability to change out or extract the treatment medium, if the attenuation capacity became exhausted;
- ability to accurately monitor inflow/outflow and water quality;

- ability to enhance the permeability of the medium in the tanks; and
- minimal impact on the landscape.

2.3 Project Design Assumptions and Medium Sourcing

For finalization of the ATS design, historical information along with bench-scale column studies were reviewed to determine areas that needed additional research before the ATS was implemented. From previous work, it was known that the NSM discharge water was circumneutral, the permeability of the treatment cells decreases over time, and the temperature of the ATS affects the performance and potentially the permeability. To assist with the design for the NSM ATS, column studies, a literature search, and a review of previously installed systems were performed.

2.3.1 Column Studies

At the Mike Mansfield Advanced Technology Center in Butte, Montana, DOE conducted column studies with water obtained from the NSM site. The objective of the column studies was to ensure the apatite medium would be applicable for treatment of the near-neutral, Zn-contaminated water (Figure 2-1). The apatite medium had not previously been tested in a neutral pH environment; prior laboratory- and field-scale studies/demonstrations had been conducted using contaminated waters with lower pH, which causes greater dissolution of the apatite material (Ref. 20).

For the study, two columns of 10% (by weight) apatite mixed with silica sand were exposed to water from the Nevada Stewart Tunnel for 2 weeks. The flow rate through one column was 5 milliliters per minute (mL/min) and the other was 10 mL/min. After the 2-week test period, Zn was breaking through at the higher flow rate, but was being retained at approximately 60% metals removal efficiency in the lower flow rate system.

Results showed that the Fe was also removed by the low flow rate test system. It was determined that the circumneutral pH had a greater detrimental effect on Zn removal due to decreased dissolution of the apatite, therefore, decreasing "reactivity" with the target ions. A second detrimental effect of the NSM water was caused by Fe deposition, which further decreases the adsorption/precipitation of Zn. After performing the column studies, recommendations for the field design included increasing the residence time by decreasing the flow rate through the system, increasing apatite concentration, or a combination of both.

2.3.2 Scale-Up for Field Design

Data/laboratory results obtained from the column study were used to provide information for the design of the ATS. Calculations were made to scale-up the volume of the treatment medium to allow for adequate residence time by controlling the flow rate through the system. The apatite concentration was also increased from 10 weight percent (wt%) to 33 wt% to provide improved adsorption/precipitation of Zn from that observed in the column study. The field system also had 66 wt% gravel. Design details can be found in MSE's DOE reports (Refs. 20 and 21).

2.3.3 Source of Apatite II™

The Silver Valley Natural Resource Trust (SVNRT) transferred ownership of a quantity of Apatite II™ material (approximately 26 cubic yards) originally obtained from PIMS NW, Inc., for use at the Success Site to the Idaho Department of Environmental Quality (IDEQ) in May 2002. Apatite II™ (U.S. Patent Number 6,217,775) is a form of cleaned fishbone apatite developed by PIMS NW, Inc.

As defined by the column studies, the amount of apatite treatment medium available from SVNRT was a limiting factor in determining the volume of contaminated water to be treated. Calculations were performed, using the information acquired during the column study, to determine the volume of water that could be treated by the ATS design. It was determined that approximately 20 gpm would be diverted and treated on a continuous basis in the ATS at the NSM. An average of 17.9 gpm was treated during system operation.

2.4 Technology Implementation

The specific tasks and specifications required to install the fully contained, subsurface retention basin (Tank 1) and treatment system (Tanks 2, 3, and 4) are described below and illustrated in Figures 2-2, 2-3, and 2-4.

All piping and tanks were emplaced below ground level to protect the ATS from freezing conditions, for odor control, to inhibit public access, and to maintain natural hydraulic flow through the system. The manhole and valve covers to the tanks were buried and insulated, and the tanks were buried at least 1 foot below ground surface. The piping was buried at least 2 feet below the ground surface, with a layer of tarpaper above the piping to provide frost dissipation.

2.4.1 Surface Water Diversion and Sediment Control

The construction of a catch basin for sediment control was completed before other construction at the site to allow for all surface water and NSM drainage to be diverted during the subsequent phases of construction catch basin. The location of the catch basin is depicted in Figure 2-3 and a cross section of the catch basin is shown in Figure 2-4. The diversion system provided a means to measure the mine discharge and flows into the treatment system and catch basin, and allowed sediment/solids to be captured before discharging to Highland Creek. The system also diverted flow under the road removing mine flow over the road and its sediment contribution from vehicles tracking through the flow.

The water diversion system consisted of liner material placed to divert the NSM drainage into a 60-degree, trapezoidal flume (Figure 2-5). The flume directed the adit drainage through two adjustable 6-inch valves. One directed flow through a 6-inch Thel-Mar weir (Figure 2-6) to measure the flow into the retention basin (and subsequently to the treatment system). The other directed flow through a bypass system and into the sediment control/catch basin system before discharging into the stream (Figure 2-2). During construction of the retention basin and treatment systems, all water was directed through the bypass portion of the system.

The sediment control/catch basin system consisted of a 25-foot by 10-foot by 5-foot deep excavation, lined with approximately 6 inches of gravel and large rock (approximately 1 to 2 inches in diameter), as shown in the cross section of the catch basin in Figure 2-7. Both the treated and nontreated water filter through the gravel/rock material and approximately 3 feet of natural stream bank vegetation (grass, trees, and low shrubs) and material before discharging into the stream. Discoloration was noticeable in the bypass.

2.4.2 Subsurface Retention Basin Design

Following the water diversion system construction, material was excavated from the area where the water retention basin and treatment systems were located. Once the site was excavated, a 3-inch sand bed was laid down as a base for all the tanks and piping. The influent from the tunnel drainage was at the highest elevation with depths increasing to the retention tank, header, treatment tanks, and post-treatment and discharge piping. Surface elevation and bottom of the retention basin was measured to ensure consistent level measurement for the tanks.

The retention basin design consisted of a buried 1500-gallon septic tank (5 feet high by 6 feet wide by 13 feet, 2 inches long) with an internal baffle to facilitate sediment settling (see the plan view of Tank 1 in Figure 2-4). Valves controlled the influent flow out through a 10-inch pipe near the top of the retention basin (Tank 1) and was directed to the treatment system via a 10-inch pipe (Figure 2-8).

2.4.3 Treatment System Design

The treatment system consisted of three 3,000-gallon septic tanks (8 feet in diameter by 10 feet long) placed in parallel so that each treatment cell/tank could accommodate a third of the flow (approximately 6 gpm) through the system (Figures 2-3, 2-4, and 2-9). Preceding each tank, an adjustable butterfly valve was used to control the flow through the apatite medium. Within each tank, two baffles were used to guide the flow through the system; the first one was placed approximately 3 feet from the tank inlet and the second one approximately 3 feet from the first baffle (Figure 2-10 and Figure 2-11). A 3-foot diameter access manhole and riser emerged from each section of the tank up to the ground surface for easy treatment medium emplacement, access, and cleanout.

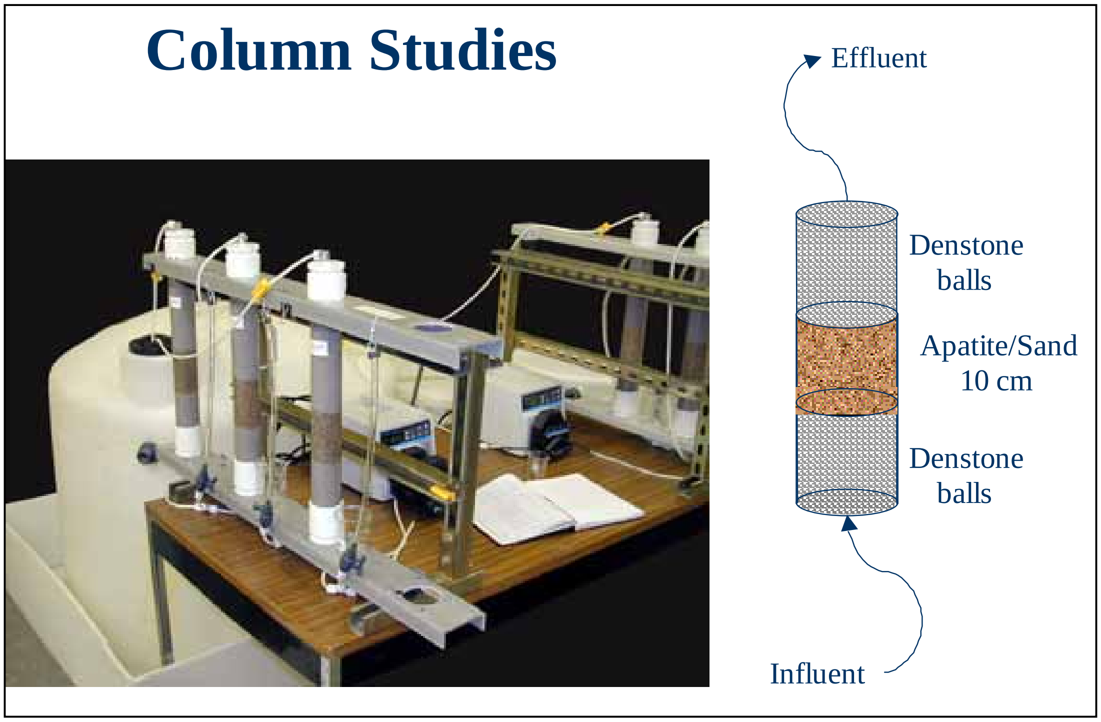
As designed, flow entered Treatment Tanks 2, 3, and 4 near the tank bottom and flowed up through the treatment medium in the first section, over the first baffle, down through the second section of treatment medium, under the second baffle, then up through the treatment medium in the third section and exited at the end of the tank near the top. Due to this flow regime, the medium was completely saturated, creating an anaerobic environment. Once the water exited the treatment cells, it flowed through sections of a 10-inch pipe equipped with a 10-inch Thel-Mar weir to measure flow. Manholes/risers functioned as sample ports [Sample Port 1 (SP1), Sample Port 2 (SP2), and Sample Port 3 (SP3)] allowing for post treatment water quality samples to be drawn for laboratory analyses.

Upon exiting the sample zone, the treated water flowed into a 10-inch pipe extending under Highland Creek road and into the catch basin before discharging into Highland Creek. A subsurface vent system was placed in the exiting piping system to promote the release of any off-gas production within the pipe. The odor control issue was addressed by passing the off-gas through a vent containing granulated activated carbon. See Figure 2-4 for cross-section of the odor control devices.

A photo of the site just after the ATS was installed is shown in Figure 2-12, a photo of the site after two years is shown in Figure 2-13, and a photo showing the system just after closure is depicted in Figure 2-14.

2.4.4 Treatment Medium Installation

The proper ratio of apatite to gravel was established based on the results of column studies performed for DOE, the system implemented at the Success Mine, and recommendations from the patent holder for the apatite medium—PIMS NW. The apatite provided by the IDEQ needed to be crushed to a smaller size fraction (< 1-¼ inch) to provide additional surface area for treatment processes to occur. To reduce the size fraction of the apatite in the medium, it was rotated in a cement mixer that acted as a grinding mill to process (crush and mix) the apatite medium (Figure 2-15). Once the medium was appropriately sized, it was mixed with the gravel. The material was then funneled into each section of the treatment tank via the manholes/risers. Approximately 24 inches of free board was left at the top of each tank. Additionally, approximately, 3 inches of gravel was placed on top of the medium to prevent flushing of the medium into the next section of the tank (Figure 2-16).



Column Studies

Effluent

Denstone balls

Apatite/Sand 10 cm

Denstone balls

Influent

Figure 2-1. Column study.

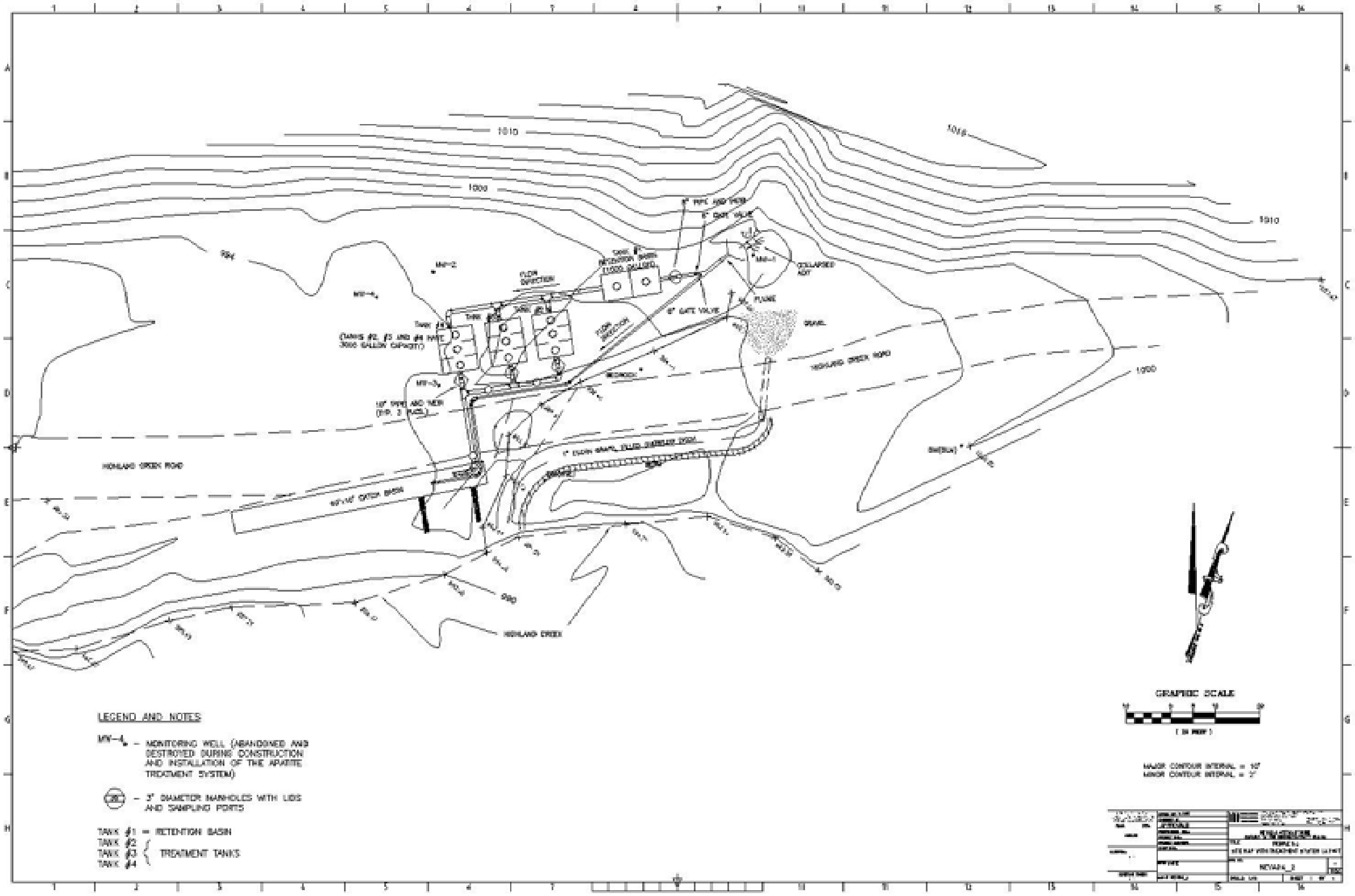


Figure 2-2. Map showing installation of the Apatite Treatment System at the Nevada Stewart Mine.

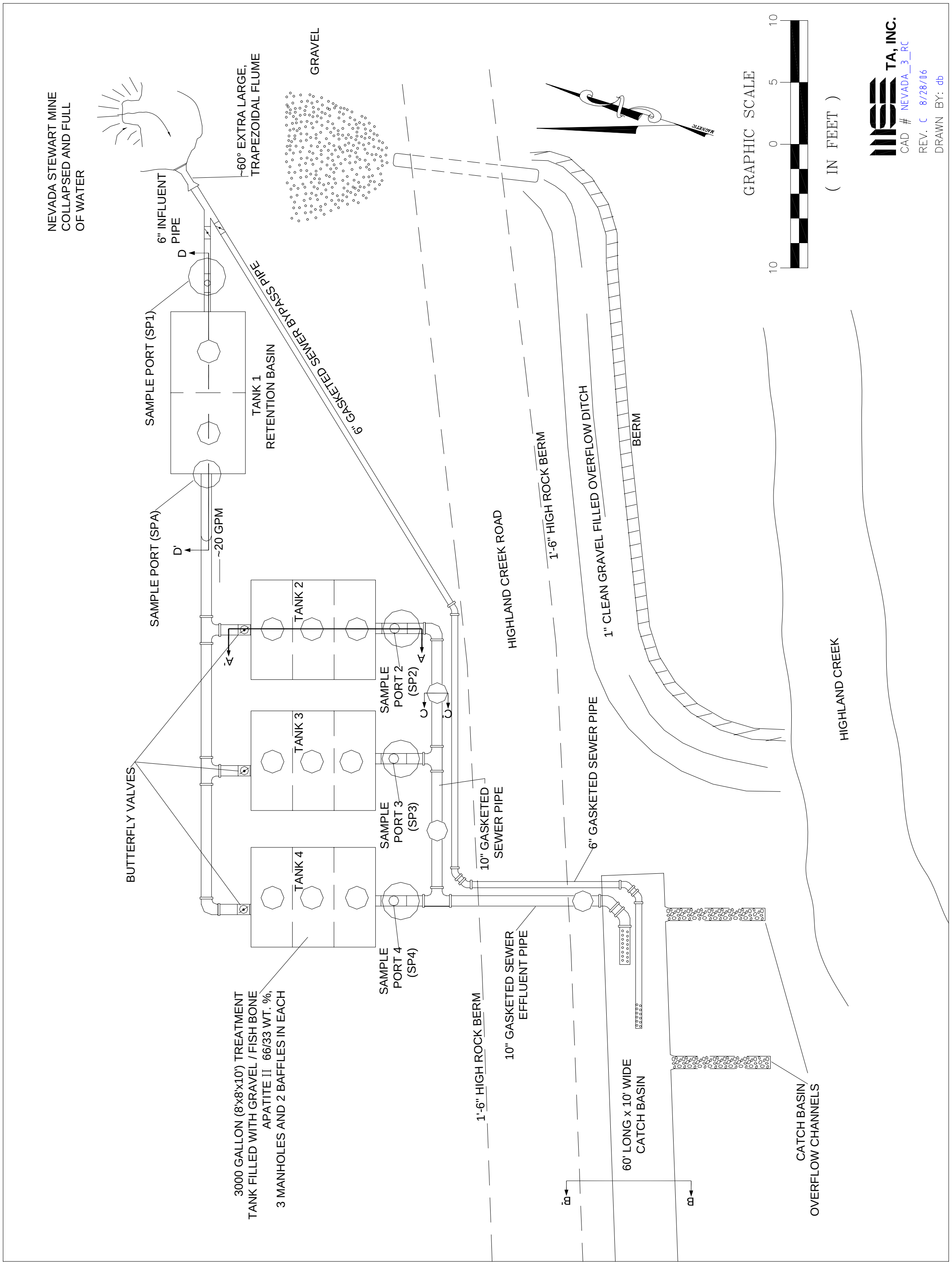


Figure 2-3. Location of sediment control system/catch basin.

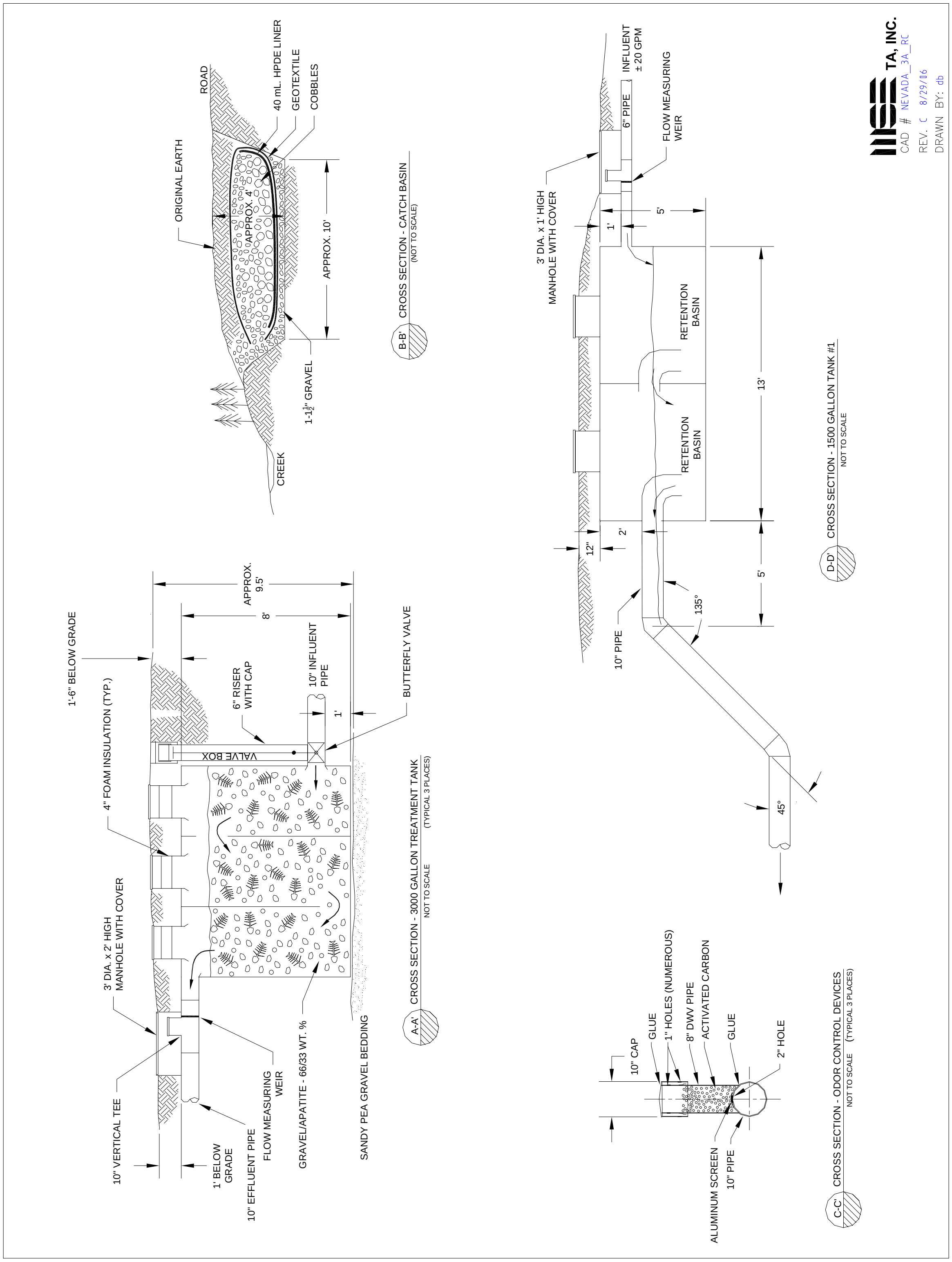


Figure 2-4. Cross-section of catch basin, retention basin, and treatment tank.

Figure 2-5. Sixty-degree trapezoidal flume used to direct NSM adit discharge through the ATS.

Figure 2-6. Thel-Mar weir and bubbler used to measure flow from treatment tanks.

Figure 2-7. ATS catch basin for effluent water.

Figure 2-8. ATS Tank 1 (retention basin) used to trap debris in water.

Figure 2-9. ATS Tank 4 being placed at NSM.

Figure 2-10. NSM ATS construction prior to covering system.

Figure 2-11. ATS system uncovered with risers and sample ports constructed.


Figure 2-12. NSM ATS just after construction looking upstream (November 2002).


Figure 2-13. NSM ATS 2 years after installation looking downstream (September 2004).

Figure 2-14. NSM ATS after closure of system.

Figure 2-15. Installation of whole-bone apatite and gravel mixture into treatment tanks.

Figure 2-16. Whole bone apatite/gravel media before submerging it with water. Note vertical baffle/partition visible in photo.

3. Performance Monitoring and Testing Methods

Several monitoring and testing methods were used to determine the effectiveness of the ATS and determine the attenuation mechanisms capable of removing metals from the NSM discharge. The performance monitoring and testing at the site included:

- monitoring system influent and effluent flow rates by MSE;
- monitoring water quality of the system flows and localized stream flows (resulting in geochemical and statistical analyses performed by Golder and EPA-NRMRL, respectively);
- testing solid phase media [including X-ray diffraction (XRD), scanning electron microscopy (SEM), total solid digestion analysis of the fishbone, and energy dispersive X-ray (EDX) analyses performed by Montana Tech];
- monitoring the influent and effluent flow for toxicity (analysis performed by the EPA-NRMRL) in 2003; and
- monitoring the influent and effluent water for bacteriological activity by the Center for Innovation (CFI).

This section describes the monitoring and testing methods used for evaluating the ATS.

3.1 ATS Flow Monitoring Design and Methods

The treatment system was designed as a watertight, closed treatment system allowing for the influent and effluent flow to be measured and the reduction in historic metal loading to be evaluated. The total discharge from the mine was measured using a 60-degree, extra large trapezoidal flume. Historically, flow measurements and background information were acquired from the Bureau of Land Management and that information indicated that the discharge from the mine adit ranged from approximately 50 to 60 gpm all year (Ref. 3).

The flow to the ATS was split into two flows immediately after the total flow was measured in the flume. The inlet pipe 6-inch valve was set to approximately 17 gpm, to a 6-inch Thel-Mar weir at (SP1) and then into the retention tank and ATS. Any flow exceeding 17 gpm was diverted through the 6-inch bypass valve and pipe and then into the catch basin (Figures 2-2, 2-3, and 2-4).

On the down-gradient effluent side of each of the treatment tanks, the effluent flow was measured using 10-inch Thel-Mar weirs [SP2, SP3, and Sample Port 4 (SP4)] (Ref. 1). The flow was measured once a month unless weather conditions or plugging of the system prohibited sampling during a specific month. Flow rate data in gallons per minute from each sampling event is provided in Figure 4-2 and in Appendix A.

3.2 Water Quality Monitoring

MSE and Golder personnel took water quality samples and flow measurements at SP1, Sample Port A (SPA), SP2, SP3, and SP4. After the mine discharge water had been split, influent water quality samples were taken at AP1 and SPA (located at the inflow and outflow of Tank 1, respectively) to check the effect of the retention tank. Effluent water quality samples were taken as the flow exited Tank 2 (SP2); Tank 3 (SP3); and Tank 4 (SP4) (Figures 2-9, 2-10, and 2-11). Water quality data from the sampling events is in Appendix A.

Monthly water samples and field parameters were taken at the site. Samples were analyzed at HKM Laboratory for specific groups of constituents. A list of the analyzed constituents is in Table 3-1.

3.2.1 Toxicity Characterization

Water samples from the NSM site were shipped to the EPA Laboratory in Cincinnati, Ohio, where a series of acute aquatic toxicity tests with *Pimephales promelas (P. promelas),* the fathead minnow, and *Ceriodaphnia dubia (C. dubia)*, a freshwater invertebrate, were conducted. The purpose of these tests was to establish the level of toxicity for the discharge from the mine site and to evaluate the effectiveness of the treatment process utilized at the site (Appendix B). MSE and Golder took toxicity samples annually, which EPA evaluated at the AAALAC Certified Aquatic Research Facility in Cincinnati, Ohio.

3.2.1.1 Methods

Samples were collected in 1-gallon containers. At least 4 liters of sample were collected from the mine discharge (SP-1), the three tank outlets in the treatment process discharge (SP-2, SP-3, SP-4) and samples upstream and downstream of treatment system. Sample containers were completely filled so no air space was left after they were capped. Samples were placed in a cooler with ice and shipped overnight to the EPA facility in Cincinnati. All coolers were received in good condition with all seals intact, and all samples were in acceptable condition. A total of four water samples were received annually, and the following standard testing conditions were followed for each set of samples (Tables 3-2 and 3-3).

3.3 Solid Phase Characterization

Montana Tech performed an in-depth literature search, XRD, SEM, and EDX analysis to determine and identify the solid materials present in the treatment media and gather information for defining the attenuation mechanisms functioning to remove dissolved metals from solution within the treatment tanks.

One of the goals of this project was to determine the mechanisms responsible for the attenuation of dissolved metals from mining impacted water using fishbone apatite.

An extensive literature search was conducted using several databases available through the Montana Tech Library. A complete listing of all documents found during the literature search is located in the Reference section of Montana Tech's final report provided in Appendix C.

Solid samples of treatment media were collected at selected depths within each treatment tank twice during the project. These samples were used to evaluate whether there was concentration stratification formed within the treatment tanks and at what depth certain metals are removed from solution. Montana Tech took the first solid samples in July 2003, and MSE collected the second set at the closure of the project in September 2004. Core samples were collected at varying depths (surface, 8, 16, 24, and 32 inches) from Tanks 2, 3, and 4 using a 2-inch diameter manual core sampler. The samples were taken from the middle section of the ATS, where flow was forced vertically downward between the baffles. The samples were stored in 1-quart Ziploc bags, labeled, and refrigerated until use. The solid samples were digested and prepared according to EPA Test Method 3050B, Method Two, *Preparation of Sediments, Sludges, and Soil Samples for the Analysis of Samples by Inductively Coupled Plasma Mass Spectrometry (ICP).* Samples were then analyzed for total metals at SVL Analytical in Kellogg, Idaho for the constituents Ca, Cd, Fe, magnesium (Mg), Mn, Pb, and Zn. The solid media sampled and digested was biased toward fishbone, meaning that the 1- to 1½-inch gravel was not analyzed or digested. Please refer to Section 4.5 for total metals results.

The bone samples collected were also analyzed using XRD and SEM/EDX. Appendix C contains the final report from Montana Tech that discusses the methods and results of the solid media analysis from the ATS.

3.4 Bacteriological Characterization

In September 2004, during the closure of the project, sulfate-reducing bacteria (SRB) samples were taken and evaluated by CFI. These solid samples were taken to determine the level of SRB activity in each of the treatment tanks at the end of the demonstration project. The SRB results by the most probable number method were used to assist with the determination of the attenuation mechanisms working within each of the treatment tanks. Coliform analysis was also conducted every month at SP1, SP4, and upstream and downstream locations in the creek.

Table 3-1. Baseline and Target Constituents Monitored at the NSM ATS

Constituent	Ports 1 to 4		Port A	Upstream/Down-Stream
	Baseline	Target	Target	Stream Target
Field Parameters				
pH	X	X	X	X
Temperature	X	X	X	X
Conductivity	X	X	X	X
Oxidation-Reduction Potential (ORP)	X	X	X	X
Dissolved Oxygen (DO)	X	X	X	X
Flow	X	X	X	X
General Parameters/Major Ions				
Alkalinity	X	X		
Acidity	X	X		
Ca	X	X	X	
Mg	X	X		
Sodium (Na)	X			
Potassium (K)	X			
Sulfate	X	X		
Sulfide	X	X		
Chloride	X			
Fluoride	X			
Dissolved and Total Metals				
Silicon (Si)	X			
Al	X			
Fe	X	X	X	
Hg	X			
Selenium (Se)	X			
Ag	X			
Thallium	X			
Cd	X	X		X
Cu	X			
Mn	X	X	X	
Pb	X	X		X
Zn	X	X	X	X
As	X			
Sb	X			
Ni	X			
Beryllium (Be)	X			
Chromium (Cr)	X			
Nutrients				
Total Ammonia	X	X		X
Nitrate	X	X		X
Nitrite	X	X		X
Kjeldahl Nitrogen	X	X		X
Dissolved Orthophosphate	X	X		X
Total P	X	X		X
Dissolved Total P	X	X		X
Bacteriological				
Coliform Bacteria[a]	X	X		X

[a] Coliform bacteria monitored at SP1 and SP4, Upstream and Downstream.

Table 3-2. Standard Test Conditions for *C. dubia* Acute Toxicity Tests with Superfund and/or Mine Waste Samples

Test Criteria	Specifications
Test Type	Static-renewal
Test Duration	48 hours
Temperature	20 °C ± 1 °C
Photoperiod	16 hours light/8 hours dark
Test Chamber Size	30 milliliters (mL) (plastic cups)
Test Solution Volume	15 mL
Renewal of Test Solution	Daily
Age of Test Organisms	Less than 24-hours old
Number of Organisms/Per Test Chamber	5
Number of Replicate Chambers/Concentration	4
Number of Organisms/Concentration	20
Feeding	None, fed while holding prior to test setup
Dilution Water	Moderately Hard Reconstituted Water (MHRW)
Endpoint	Mortality, LC50
Test Acceptability	≥ 90% survival in the controls

Table 3-3. Standard Test Conditions for *P. promelas* Acute Toxicity Tests with Superfund and/or Mine Waste Samples

Test Criteria	Specifications
Test Type	Static-renewal
Test Duration	48 hours
Temperature	20 °C ± 1 °C
Photoperiod	16 hours light/8 hours dark
Test Chamber Size	175 mL (plastic cups)
Test Solution Volume	150 mL
Renewal of Test Solution	Daily
Age of Test Organisms	5 days ± 24-hour age range
Number of Organisms/Per Test Chamber	10
Number of Replicate-Chambers/Concentration	2
Number of Organisms/Concentration	20
Feeding	Feed newly hatched brine shrimp prior to testing; do not feed during the test
Dilution Water	MHRW
Endpoint	Mortality, LC50
Test Acceptability	≥ 90% survival in the controls

4. ATS Performance Monitoring Results

4.1 Flow Volume Results

The ATS was designed as a watertight (closed) treatment system that allowed the effluent and influent flow rates to be measured. A conservative estimate of the total volume of flow treated by the ATS was approximately 13.4 million gallons. The flow for the months of December 2002 through February 2003, when the ATS was plugged, along with the month of January 2004, when weather prevented access to the site, was not included in this total flow volume estimate. While the system was designed to treat 20 gpm, the average flow rate through the system was approximately 17.9 gpm, and this flow varied on a monthly basis (Table 4-1). Treatment Tank 3 treated 48.6% of the flow going through the system (an average flow rate through media was 8.7 gpm); Tank 2 treated 33% of the system flow (an average flow of 5.9 gpm); and Tank 4 treated the least amount of flow, approximately 18% (an average flow rate of 3.3 gpm) (Table 4-1).

Flow through the system was variable due to seasonal fluctuations and the changes in permeability within certain tanks due to settling, increased precipitation of metals, and air sparging of the system that was done to improve the permeability and create new flow pathways through the media. An air compressor with a long lance attachment that could be inserted into the media beds was used to agitate the media. The flow responses to the permeability enhancements conducted in the ATS are presented in Figure 4-1. In this figure, the influent flow reflects seasonal peaks, which occurred during April and May of both project years. May 2003 had the highest volumetric flow through the system at 1.3 million gallons (Figure 4-2). After May 2003, the tanks started to plug for the second time, and air was injected to enhance and restore permeability in the ATS. After May 2003, Tank 2 (SP2) recorded the highest flow values for a period of 3 months; after that period, Tank 3 again treated the majority of the system flow, with some minor fluctuations.

The ATS was plugged from December 2002 to February 2003, and samples were not collected in either December 2002 or January 2003. In February 2003, samples were collected, but those results reflect the conditions of a plugged system, not a properly functioning system. Also, samples were not collected in January 2004 due to adverse weather conditions. An additional sampling event was scheduled and conducted in April 2004 (i.e., samples were taken on April 1 and 29, 2004).

4.2 Water Quality Monitoring Results

Monthly sampling was performed at the Nevada Stewart ATS from November 2002 through August 2004. The main influent sampling location sample port (SP1) and the effluent sample ports (SP2, SP3, and SP4) were sampled monthly (Figure 2-3). Sample Port A was sampled annually to determine the amount of metals removed in Tank 1, the retention basin. The water quality samples were analyzed by HKM Laboratory and personnel acquired the field parameters such as pH, ORP, specific conductivity (SC), DO, and temperature. The complete water quality data set for the project is presented in Appendix A.

Since the permeability of the system declined throughout the project due to media settling and metals precipitation, the permeability in the treatment tanks was improved using air-sparging/injection techniques a number of times. Air was injected into the media through the manholes to lift the media, resulting in the creation of alternative and larger flow pathways. The permeability of the ATS was enhanced after sampling was conducted in February 2003, May 2003, October 2003, and April 2004.

Performance monitoring results and observations are presented in this section in the following order:

- pH and Alkalinity;
- Temperature and SC;

- Redox Conditions (ORP, DO, ammonia, and sulfide);
- Major Ions (Ca, Mg, and sulfate);
- Metals (Zn, Cd, Pb, Fe, and Mn);
- Nutrients (P and nitrogen); and
- Bacteriological (coliform and SRBs).

4.2.1 pH and Alkalinity

Over the duration of the project, there was a seasonal cycle in pH observed for the influent water (Figure 4-3). The ATS influent pH ranged from 5.3 to 7.0. Influent pH values increased throughout the fall of 2003 remaining stable over the winter months at levels comparable to the winter values observed in 2002 (i.e., pH values from 6.1 to 6.7). This seasonal cycle was repeated in 2004.

For the ATS effluent flows, the average pH ranged from 6.0 to 7.0, except during two instances. The first instance occurred during the period between December 2002 and February 2003, when the ATS system was clogged. Flow throughout the system was restored in February 2003; however, the conditions of the system, as a result of the clogging, were reflected in the pH values recorded from the February 2003 sampling data (Figure 4-3). At that time, the pH at SP4 was alkaline (pH of 8) and the pH of other treatment cells was approximately neutral (pH of 7). The effluent pH values recorded on April 29, 2004 and May 25, 2004, were lower than historically recorded. On April 29, 2004, effluent pH values ranged from 5.3 to 5.5 and were lower than the measured influent pH.

The alkalinity of the effluent water was slightly less than that of the influent waters (Figure 4-4). The most significant difference in alkalinity was observed just after the ATS was installed in November 2002. Sample Port 4 consistently recorded slightly higher alkalinity, up to approximately 30 milligrams per liter (mg/L) more than SP1, SP2 and SP3, with the exception of November 2003 and March to early April 2004, when SP3 samples had higher alkalinity.

4.2.2 Temperature and Specific Conductivity

Minimal variability of the water temperature from the NSM discharge (the influent) and the effluent from the ATS was recognized throughout the project duration; the difference was typically less than 1 °C and the maximum difference was 2.8 °C. The flow from the underground workings had a fairly constant temperature and did not exhibit seasonal fluctuations. However, the temperature fluctuations of Highland Creek, due to seasonal conditions, were dramatic and a graphed representation is provided in Figure 4-5, where US depicts values from the upstream monitoring location and downstream (DS) depicts values from the downstream monitoring location (Figure 2-2).

The SC for the NSM adit discharge, the ATS, and Highland Creek show minimal variability. The main fluctuations recorded were on February 2003 when the system was plugged and on April 29, 2004, and the reason for an outlier cannot be defined (Figure 4-6).

4.2.3 ORP, DO, Ammonia, and Sulfide

The influent from the NSM adit into the ATS was slightly oxidized, as indicated by the presence of DO ranging from 6 to 11 mg/L and by the positive ORP values ranging from 160 to 320 mV (Figures 4-7 and 4-8). Influent ORP values fluctuated seasonally; thus, the ORP values were lower in November and during the springtime runoff/snowmelt periods. The ORP of the effluent waters during the first year of monitoring indicated a change toward reducing conditions, ranging from –90 to 230 mV. From November 2003 to project closure, Tank 2 and 3 maintained higher recorded ORP values (150 mV) than Tank 4, which became increasingly reducing at the closure of the project (ORP < 100 mV). Between November 2003 and April 29, 2004, differences between influent and effluent ORP were minimal (< 10 mV difference). Air sparging did not appear to affect effluent ORP values, an increase in ORP was not consistently observed following sparging events.

Comparisons of the effluent water qualities, indicates variability in the redox conditions between treatment tanks. Although all treatment tank effluent data shows a decline in DO relative to the influent, since May 2003 greater reductions in DO were typically observed in SP2 and SP4 compared to SP3 (Figure 4-7).

The 2004 effluent monitoring results show fairly low sulfide concentrations for all treatment tanks, ranging from below detection limits (< 0.5 to 2 mg/L). Low levels of ammonia (up to 0.2 mg/L) and sulfide (up to 1.6 mg/L) were recorded at SP1 (Figures 4-9 and 4-10 or Appendix D). Over the total monitoring period, a general decline in effluent sulfide concentrations have been observed. Except at SP4 from April 29, 2004 until the project closure, recorded ORP values declined while sulfide, ammonia, and bacteria (coliform) concentrations increased.

Throughout 2003, SP4 consistently recorded the highest sulfide concentrations (Figure 4-10). On the basis of increased sulfide content, SP4 provided data consistent with enhanced SRB activity.

4.2.4 Major Ions

Calcium, Mg, and sulfate were included in the target analyte suite. Calcium concentrations in the influent were relatively stable, ranging from 83 to 103 mg/L. Effluent waters reported slightly higher Ca concentrations, up to 111 mg/L (Figure 4-11).

Monthly monitoring results showed little difference between Mg influent and effluent concentrations, typically less than 1 mg/L (Figure 4-12).

Declining sulfate concentrations were observed between the influent and effluent samples; generally, the declining sulfate concentrations coincided with increasing sulfide concentrations. On a monthly basis, the sample port reporting the highest concentration in sulfide reported the greatest decline in sulfate (Figure 4-13).

4.2.5 Metals

The ATS appears to have effectively attenuated Zn, Mn, Fe, Cd, and Pb (Figure 4-14). However, due to the variability of flows through each treatment tank, the results obtained reflect the effect of the variability with respect to metals concentration, retention time, and attenuation mechanisms functioning in each tank.

Zinc

Over the duration of the ATS monitoring project, the influent dissolved Zn concentrations from samples taken at Tank 1 have gradually increased from approximately 5.5 to 8.0 mg/L (Figure 4-15). Dissolved Zn at Tank 2 ranged between nondetect and 5 mg/L (Figure 4-15). Tank 3 ranged between nondetect and 6 mg/L. Tank 4 ranged between nondetect and 1.5 mg/L. The effluent dissolved Zn concentrations were below 5 mg/L for both Tanks 2 and 4. Between November 2003 and April 2004, Tank 4 effluent Zn concentrations gradually increased, coinciding with the increase in DO, indicating a change to more oxidizing conditions. The Zn concentrations for Tanks 2 and 4 gradually increased over the duration of the project. Tank 4 reduced the Zn concentrations below 0.1 mg/L for over a year and then the maximum Zn concentration recorded was 1.6 mg/L during the April 29, 2004, sampling event. At the closure of the project (August 17, 2004) the Zn concentrations were approximately 0.1 mg/L at Tank 4.

However, Tank 3 exceeded the 5 mg/L after 11 months (i.e., effluent Zn concentration ranged from 1 to 6 mg/L) and after treating 3.5 millions gallons of NSM water (Figure 4-15), provided the least Zn attenuation. The effluent Zn concentrations were reduced when air was entrained into the treatment tanks to improve the permeability of the apatite media.

The Highland Creek Zn concentrations were higher downstream of the ATS. This results from waste material at the site and untreated adit discharge that bypassed the system. Between 50% and 65% of the untreated discharge enters

Highland Creek up-gradient of the downstream sampling location. It should be noted that only 17 gpm of the approximately 40 to 60 gpm flow discharging from the NSM adit was treated by the ATS.

Iron

Dissolved iron concentration in the discharge was relatively low. For applications with higher dissolved iron concentrations, iron precipitates will likely clog the treatment media. On average, the influent concentration for Fe recorded at Tank 1 was approximately 0.6 mg/L. However, concentrations varied between 0.2 and 0.9 mg/L. Lower iron concentrations were recorded for the effluent flows than the influent flows for the full duration of the project (Figure 4-16). Over the duration of the project, there were significant variations between the treatment tanks. At Treatment Tank 2, the Fe concentrations did not exceed 0.2 mg/L for the project duration, and permeability enhancements reduced the Fe concentrations except on May 2003 when flows were uncharacteristically high. Higher Fe concentrations were recorded when the system was partially clogged.

Tank 3 iron concentrations peaked from May to October 2003. During this period, large quantities of water were treated in Tank 3. Air enhancements decreased the concentrations of Fe every time at Tank 3.

Tank 4 iron concentrations exceeded 0.2 mg/L only twice, in June and July 2004. Peak concentrations coincided with the increase in dissolved Fe concentrations in the influent. Permeability enhancements effectively reduced the concentrations of dissolved Fe in the effluent until April 2004, when the Fe concentrations increased at SP4, which correlates to very low ORP values and increased sulfide concentrations.

Manganese

The concentration of dissolved Mn in the influent to the ATS was approximately 0.6 mg/L on average with only minor variations through the project duration (Figure 4-17). The effluent dissolved Mn concentration for Tank 2 ranged between a maximum of 0.42 mg/L and a minimum of 0.071 mg/L.

The effluent dissolved Mn concentrations in Tank 3 ranged from a maximum of 0.5 mg/L during April and May 2003 to a minimum of 0.092 mg/L in June of 2004. It should be noted that Tank 3 treated 0.85 million gpm during April and May 2003 compared to 0.15 million gpm in June 2004. Additionally, permeability enhancements reduced the Mn concentrations significantly in Tank 3, lowering the resultant concentration each time it was performed (Figure 4-17).

Tank 4 dissolved Mn concentrations ranged between a maximum level of 0.384 mg/L to a minimum of 0.155 mg/L. The concentration at Tank 4 increased after air enhancement of the ATS. However, as time progressed, the Mn concentration decreased until another permeability enhancement was initiated.

Cadmium

Observed influent concentrations for Cd were very low at < 1 part per billion (ppb) (Figure 4-18). Dissolved concentrations monitored in the effluent water were generally below the detection limits.

The highest Cd concentrations recorded for this project were those in Highland Creek, both in the upstream and downstream samples. The concentration of Cd in the ATS effluent was at or below the laboratory instrumentation detection limit. The highest Cd concentrations occurred in the winter of 2003, from November 2003 to April 2004, from samples collected in Highland Creek.

Lead

The influent concentrations for Pb were also very low, 0.0005 to 0.0023 mg/L (Figure 4-19). From November 2003, the concentration of Pb in the effluent was at or below the laboratory instrumentation detection limit. The highest Pb concentrations in the treatment effluent were in June and July 2003 just after the ATS air enhancement was performed.

The highest Pb concentrations recorded for this project were those in Highland Creek, both in the upstream and downstream samples. The Pb concentrations for Highland Creek were always higher than the influent Pb concentrations from the NSM. During the initial months of the project, the Pb concentrations downstream were higher than Pb concentrations upstream. In May 2003, this trend reversed and higher concentrations of Pb were detected upstream and lower concentrations were recorded downstream of the ATS (Figure 4-19).

4.2.6 Nutrients

As expected, an increase in P concentrations was detected in the effluent when compared to the influent (Figure 4-20). However, the total phosphorous in Highland Creek, upstream was near that of the downstream samples. However, on July 2003 and September 2003, the Highland Creek upstream total P values exceeded the downstream values from 0.2 mg/L to as much as 5 mg/L.

The total nitrogen in the effluent was also higher than in the influent (Figure 4-21). The highest nitrogen concentration in the effluent was reported in November 2002 during the initial start-up month for the ATS in Tank 4. Tanks 2 and 4 recorded the highest nitrate/nitrite values, but all were below 1.5 mg/L.

Plots of dissolved orthophosphate and Kjeldahl nitrogen are provided in Figure 4-22 and Figure 4-23. The dissolved orthophosphate concentrations are much higher in Tank 4 than Tanks 2 and 3 for the full duration of the project. Tank 3 was 38 mg/L and SP2 was 8 mg/L. These concentrations decreased after the system was unplugged in February 2003. As the system was restarted, the recorded concentrations were below 2 mg/L (Figure 4-22). Peak concentrations occurred in July 2004 just before closure of the project.

Kjeldahl nitrogen was highest in November 2002 in Tank 2 and Tank 3, when the ATS was brought on-line. Injection of the air into the ATS changed which tank provided the highest monthly source of Kjeldahl nitrogen. Initially, Tank 3 provided the highest source of Kjeldahl nitrogen, but after unplugging the system, Tank 4 recorded higher values, then Tank 2. Changes are concurrent with air injection into the ATS to enhance permeability (Figure 4-23).

4.2.7 Bacteriological

Influent and effluent total coliform concentrations, measured at SP4, are shown in Figure 4-24. See also Figure 13 in Golder's report in Appendix D. Influent total coliform concentrations typically ranged from below detection limits (< 1 per 100 mL) to less than 10 per 100 mL. The July 2004 influent total coliform concentrations were anomalously high at 140 per 100 mL. The total coliform was generally less for the influent than the effluent. Peak effluent total coliform was measured in March 2003 at 500 per 100 mL; June 2003 at 467 per 100 mL; March 2004 at 30 per 100 mL; and July 2004 at 500 per 100 mL. Total coliform values from SP4 exceeded the coliform values from Highland Creek, both upstream and downstream, on the months listed above. Otherwise, the treatment tank coliforms were less than the coliform values recorded for the stream.

The results of the single SRB enumerations are shown in Table 4-2. These results of the microbiological analyses are from samples taken on September 29, 2004. The samples were analyzed for SRB using a most probable number (MPN) assay. Results indicate that SRBs were not active in the influent samples or in the effluent from Treatment Tank 3. However, viable quantities of SRBs were present in the effluent from Treatment Tanks 2 and 4.

4.3 Geochemical Modeling

Geochemical modeling was conducted by Golder. Section 4.4 is taken from the Golder report. Golder also prepared interim reports throughout the study. The complete report provided by Golder is in Appendix D. This model has the ability to simulate mixing of water, precipitation/dissolution of selected solids, redox reaction, atmospheric interaction, and adsorption of metal onto iron oxides. The MINTEQA2 thermodynamic database was selected for this project because it is considered by many in the geochemical and regulatory communities to be the most accurate geochemical database currently available. The fast reaction kinetics of hydroxyapatite dissolution (Ref. 22) supports the application of an equilibrium model.

4.3.1 Speciation Modeling

Calcium, phosphorus, and nitrogen showed net increases, while iron, manganese, zinc, and aluminum showed net declines (see Table 4-3).

To evaluate possible controlling mineral phases, inflow and outflow water chemistries were speciated and saturation indices evaluated. Concentrations of constituents reported as below detectable limits were assumed equal to the detection limit during the modeling exercise. The potential for mineral precipitation was assessed using the saturation index provided in Appendix D and shown in Table 4-4 for August 2004.

4.4 Solid Phase Sampling Results

During the implementation of the ATS, three 5-gallon samples of treatment tank material (unused fishbone and gravel) were taken as the media was placed into the treatment tanks from the cement mixers (Figures 2.15 and 2.16). One representative sample was taken from each tank. For each bucket, the fishbone and gravel was separated, weighed, and the volumes were calculated.

Results showed that the unused media was 66.7% fishbone by volume, and 30.2% fishbone by weight; and the unit weights of the fishbone and gravel were calculated to be 20.85 pounds per cubic foot (pcf) and 94 pcf, respectively.

For the ATS treatment system, the total weight of the gravel used was 10 tons and the total weight of the Apatite II™ was 5 tons. Equal quantities of gravel and fishbone were distributed through each treatment tank.

4.4.1 Total Digestion of Fishbone from ATS

Fishbone samples from Tanks 2, 3, and 4 were digested and analyzed to determine the total concentrations of contaminants contained on the fishbone.

Digested fishbone samples from each tank were sent to SVL Analytical in Kellogg, Idaho for the analysis of Zn, Cd, Pb, Fe, Mn, Mg, and Ca. The results for the solid phase digestions are presented in Appendix E.

The results obtained from the digest analysis indicate an increase in the concentrations of Zn, Cd, Pb, Fe, and Mn compared to fishbone that was not exposed to the contaminated water (Figures 4-25, 4-26, 4-27, 4-28, and 4-29). See also Figure 21 in Golder's report in Appendix D. Untreated fishbone samples 1, 2, and 3 were obtained from each of the treatment tanks during the installation of the ATS. Comparing these samples to the treated fishbone samples collected from each treatment tank after NSM discharge was treated, the concentrations of Zn increased by an average of 97 times; Mn by 48 times; Fe by 18 times; Pb by 12 times; and Cd by 4 times. Magnesium and Ca were the only elements analyzed that decreased in concentration (Figures 4-30 and 4-31). Also, see Figure 7 from the Golder Report contained in Appendix D.

As can be seen in Figures 4-25, 4-26, 4-27, 4-28, and 4-29, Cd, Pb, Fe, and Mn concentrations were highest at the top or surface of the media placed in the tanks. However, Zn concentrations varied with depth throughout the entire sampled interval.

4.4.2 X-Ray Diffraction

Samples from Tanks 2, 3, and 4, and a sample of the uncontaminated (raw) fishbone were analyzed using XRD to identify any crystalline structures present in the treatment media.

The analysis confirms the composition of the bone as poorly crystalline hydroxyapatite. The samples analyzed from Tanks 2, 3, and 4 had no detectable crystalline structures other than that of the hydroxyapatite itself. If any crystalline materials are being produced in the reactor, the mass of the crystalline structure was too small to detect, or the materials are amorphous and could not be detected using XRD. Figure 4-32 is a representation of the graphs produced from the XRD analysis. The graphs from all samples were virtually identical.

4.4.3 Scanning Electron Microscopy/ Energy Dispersive X-Rays

Analysis using SEM/EDX was performed on the raw fishbone as well as the contaminated fishbone from each treatment tank. Analyses were performed at Montana Tech, Butte, Montana, and Image and Chemical Analysis Laboratory, Bozeman, Montana.

4.4.3.1 Unreacted (Raw) Fishbones

A sample of uncontaminated fishbone was analyzed using SEM/EDX. Results from the EDX analysis identified the primary composition of the raw fishbone as oxygen, carbon, Ca, and P, which are the primary elements found in hydroxyapatite. The results are shown in Figure 4-33.

4.4.3.2 Treatment Tank 2

The results from several of the bone samples in Treatment Tank 2 have similar trends. Zinc was the focus during this project due to the concentrations found in the influent water and on the reacted fishbones. Zinc accounts for approximately 6% of the total sample mass within the scanned area. The EDX analysis also shows a weight percent increase in sulfur. This trend was common in all samples analyzed. The remaining mass can be attributed to Ca, Al, P, silica, and several other metals. Figure 4-34 is a spectrum of the scan area on the bone from Treatment Tank 2.

Specific “bright spots” observed using the EDX backscatter option on the SEM were analyzed from a fishbone sample from Tank 2. The results from the EDX analysis show that the scan of the selected spot is made up primarily of oxygen, Zn, and sulfur. The Zn accounted for approximately 18% of the total weight within the scan area, while sulfur accounts for roughly 10%. Figure 4-35 is the EDX scan of a bright spot from Tank 2.

4.4.3.3 Treatment Tank 3

The bone samples analyzed from Treatment Tank 3 demonstrated similar results to those from Treatment Tank 2. Zinc is attributing roughly 6% of the total weight within the scan area, while sulfur contributes about 3% after treating a volume of 2.85 million gallons of water as of July 2003. An additional fishbone sample from Tank 3 was analyzed using the backscatter detector. The EDX analysis of a bright spot shows that Zn accounted for approximately 16% of the total weight, similar to the 18% found in Tank 2. Scans and data from Tank 2 can be found in Appendix C.

4.4.3.4 Treatment Tank 4

The bone samples analyzed from Tank 4 are again similar to those analyzed from Tanks 2 and 3 in that the surface of the bone particles was enriched in both Zn and sulfur within the area scanned when compared to the unreacted bone. Treatment Tank 4 had an average Zn weight percent on the bone surface of roughly 17% and a sulfur weight percent of approximately 13% after treating a volume of 1.5 million gallons of water as of July 2003. The resulting average value was based on scanning the entire surface of the fishbone not just one location (Figure 4-36).

Table 4-5 provides the results of the EDX analysis for a fishbone sample taken from Treatment Tank 4.

The backscatter detector was also used to look at a sample of fishbone from Treatment Tank 4. In addition, a comparative analysis was performed between one of the “bright spots” and a section of dark surface. Figure 4-37 is an image showing the two scanned areas. Tables that follow represent the weight percent of various elements found within the bright and dark regions.

Results from Table 4-6 show that the bright spot that was analyzed is 36.5% Zn and 17.4% sulfur. These two elements account for more than half of the total weight percent in the area that was scanned. Results from Table 4-6 show that the dark region that was scanned is approximately 6% Zn, while sulfur is roughly 5% of the total weight.

For confirmation of the presence of ZnS, a fishbone sample taken from Tank 4 was analyzed under high vacuum using the SEM. Figure 4-38 is an image of ZnS crystals that were formed on the surface of a fishbone sample from Tank 4. This image is magnified 9,000 times and has a scale of 300 nanometers.

The spherical structures within the image were identified as ZnS crystals. Previous research performed identified similar shaped ZnS crystals in an anaerobic treatment system. Raw Fishbone date in represents an EDX analysis of Figure 4-38. The Zn accounts for over 36% of the total weight within that scan region, while sulfur contributes over 17% of the total weight.

Since ZnS is being precipitated in the ATS, it can be stated that Cd and Pb may also precipitate as metal sulfides. If concentrations of Zn, Cd, and Pb were equal, the solubility products for each metal could predict this. This is due to the solubility products of each metal. Zinc sulfide is the most soluble, which indicates that cadmium sulfide (CdS) and PbS should precipitate before ZnS. Table 4-7 is a list of the solubility products of Cd, Pb, and Zn.

4.5 Toxicological Sampling Results

Water samples from the NSM site in Idaho were shipped to the EPA Laboratory in Cincinnati, Ohio for toxicity testing in 2003 and 2004. A series of acute aquatic toxicity tests with *P. promelas*, the fathead minnow, and *C. dubia*, a freshwater invertebrate, were conducted with these samples. The purpose of these tests was to establish the level of toxicity for discharge from the mine site and to evaluate the effectiveness of the treatment process currently being used at this site.

Routine initial chemical parameters were determined and toxicity tests were started upon arrival of the samples. The tests with *P. promelas* and *C. dubia* were 48-hour renewed acute tests, conducted at 20 °C. Each sample was analyzed using both species.

All tests were conducted using moderately hard, reconstituted water as the control and dilution water. Appendix B contains summaries of all initial and final chemistries and results for toxicity tests.

All LC50 values were determined using the EPA statistical analysis disk and Trimmed Spearman-Karber Program, Version 1.5, which adjusts for control mortality. The survival no observed acute effect level (NOAEL) was determined using the EPA statistical analysis disk and Dunnett’s Program, Version 1.5.

Table 4-8 summarizes the toxicity results for the 2003 and 2004 samples. The results from the tests indicate that the treatment system being used to remediate the waste from this mine site reduced the toxicity of the effluent water over that of the influent water. Refer to Appendix B for the complete toxicity results.

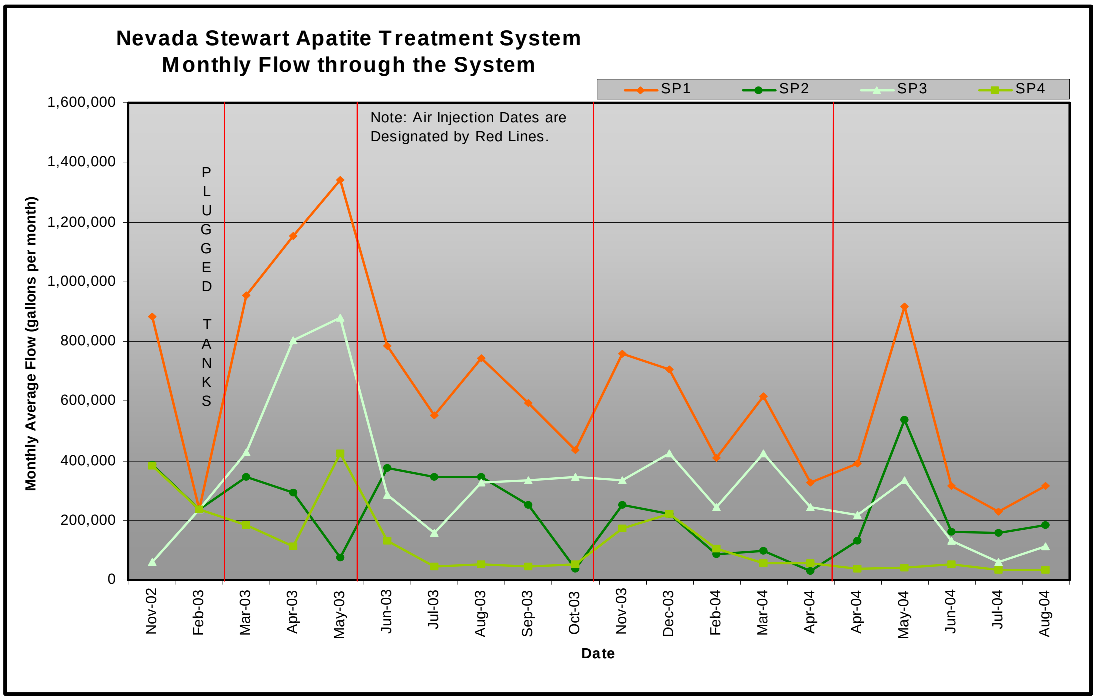


Figure 4-1. NSM ATS flow through system in gallons per minute.

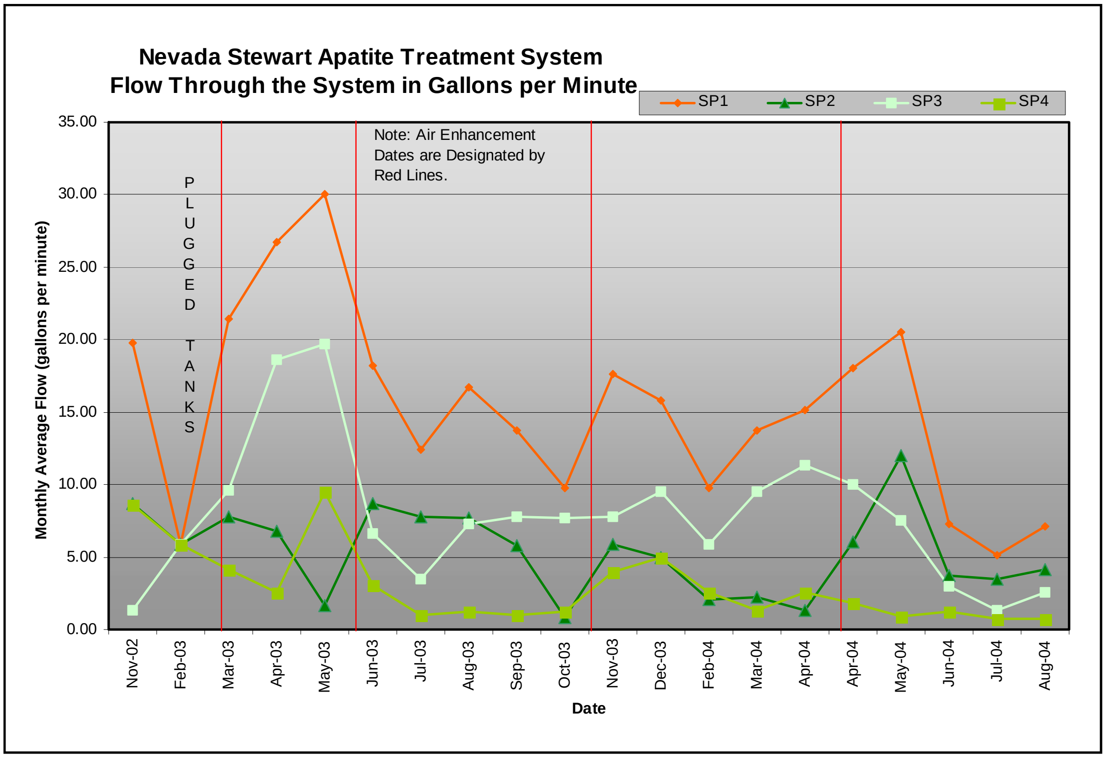


Figure 4-2. NSM ATS monthly flow through system.

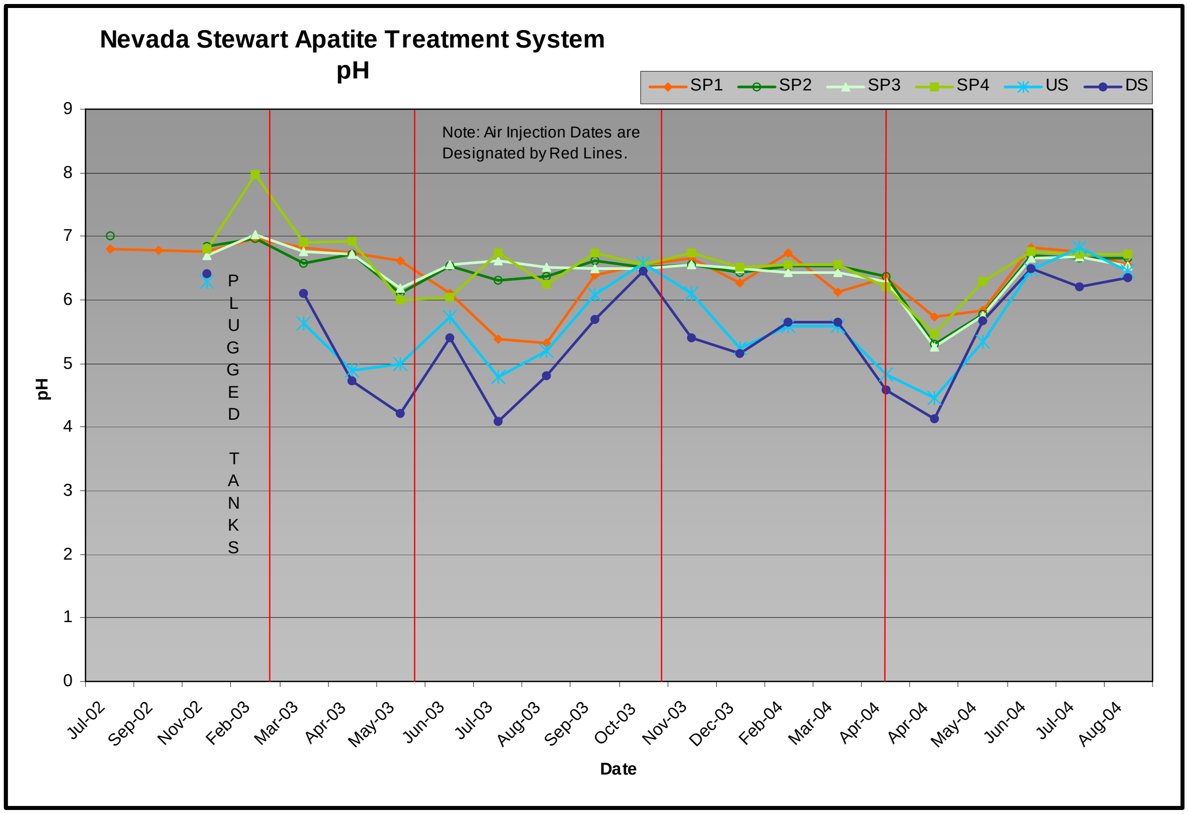


Figure 4-3. NSM ATS pH levels.

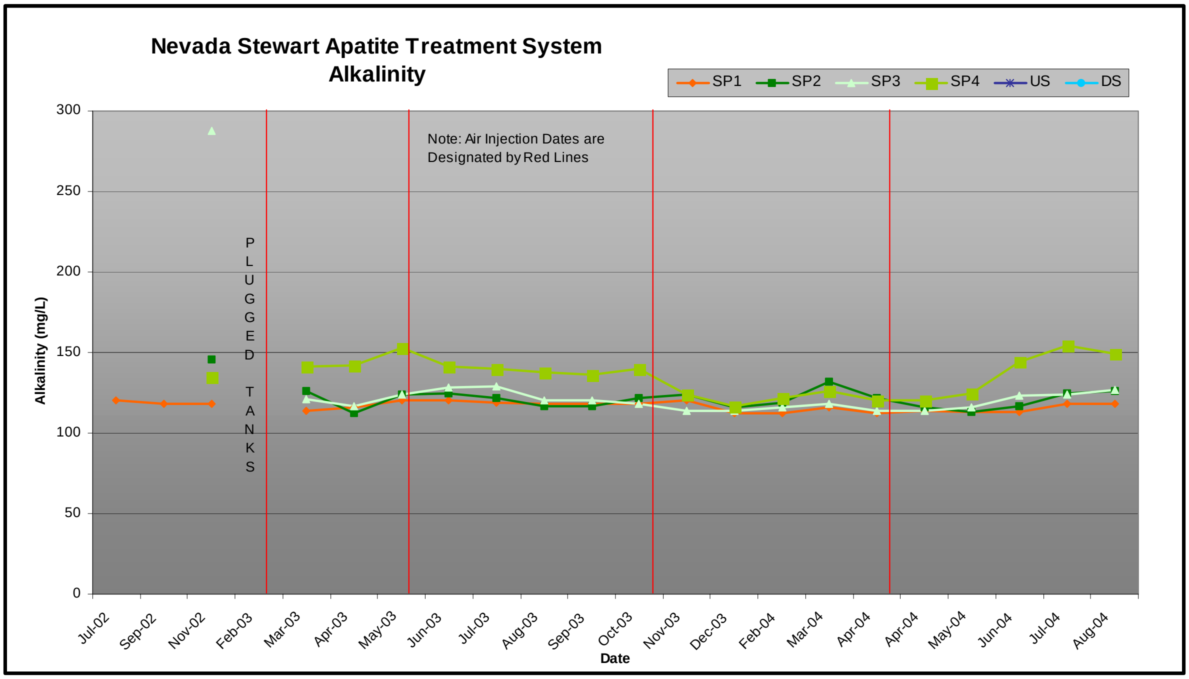


Figure 4-4. NSM ATS alkalinity.

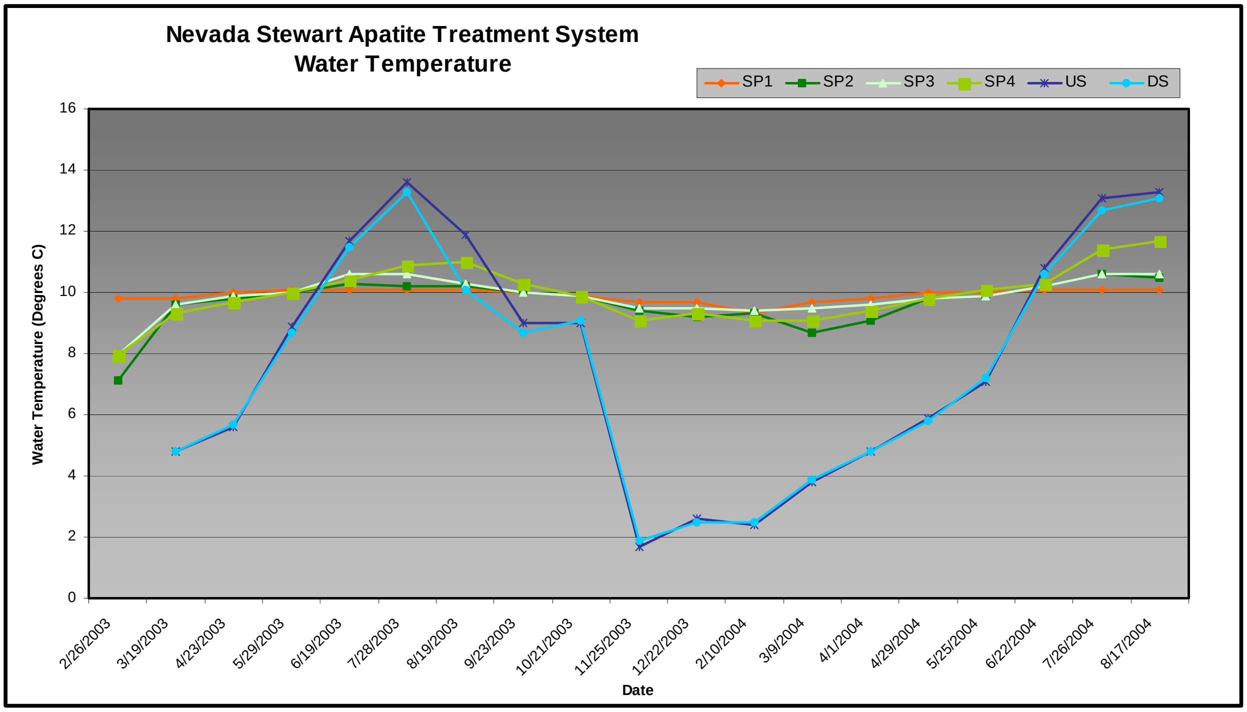


Figure 4-5. NSM ATS water temperature.

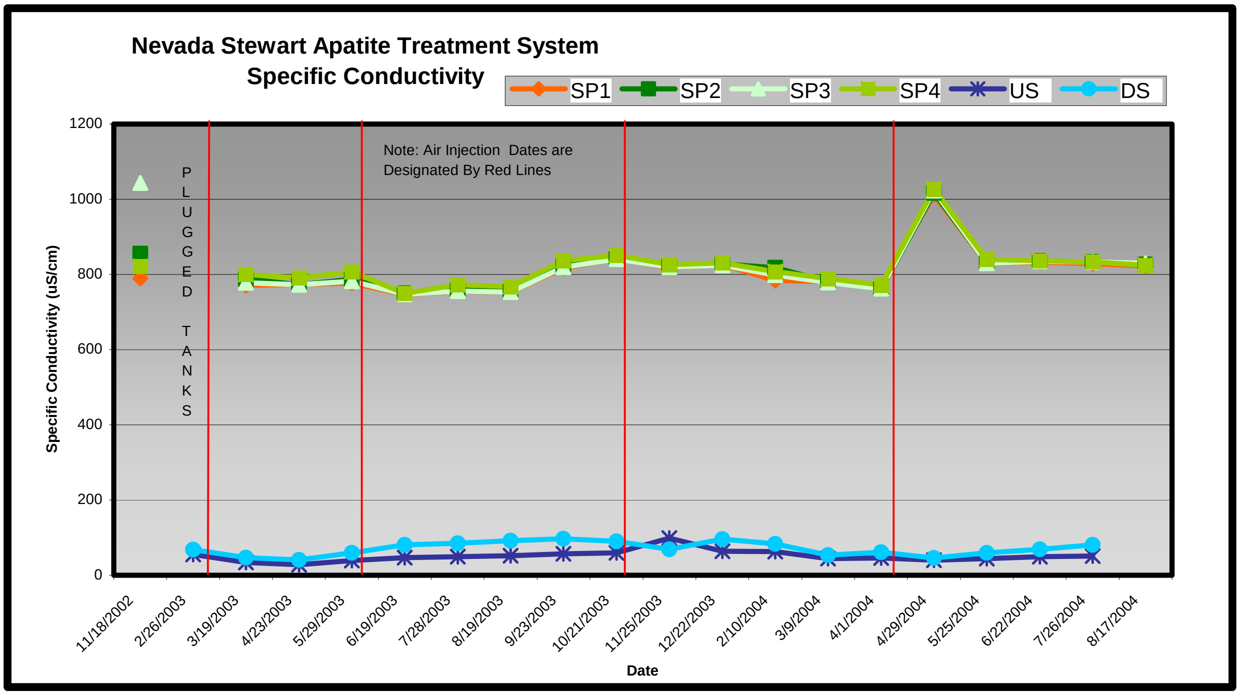


Figure 4-6. NSM ATS specific conductivity.

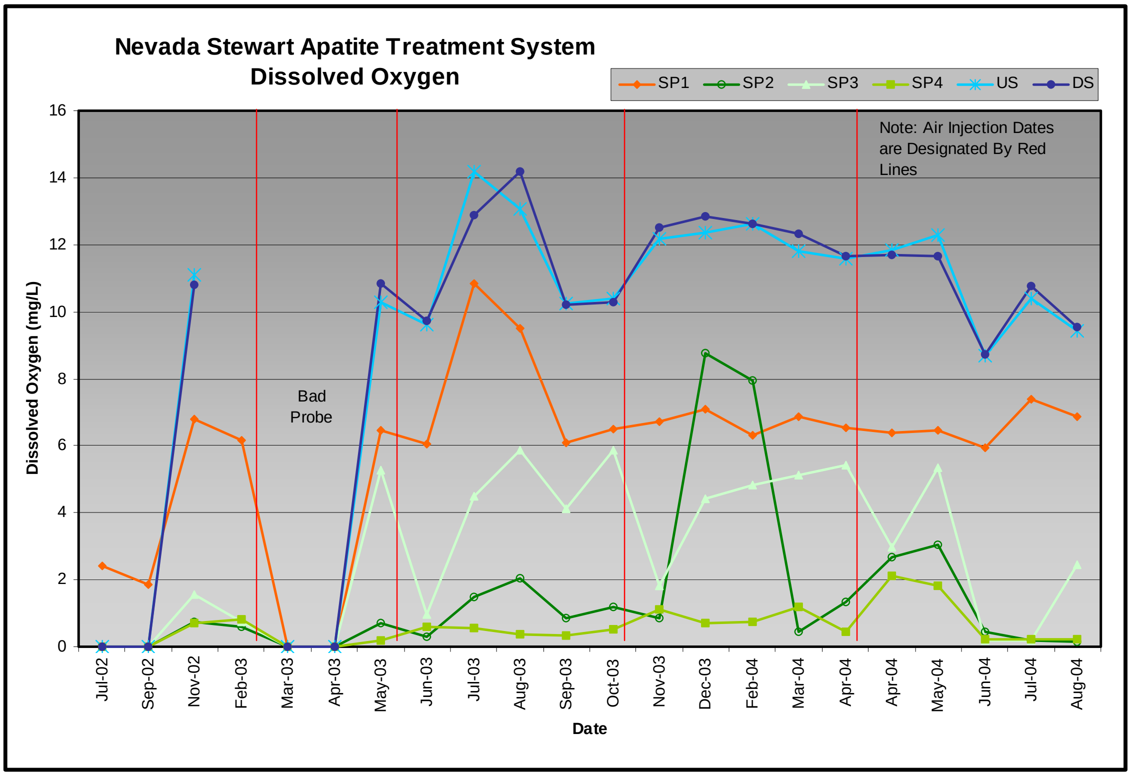


Figure 4-7. NSM ATS dissolved oxygen.

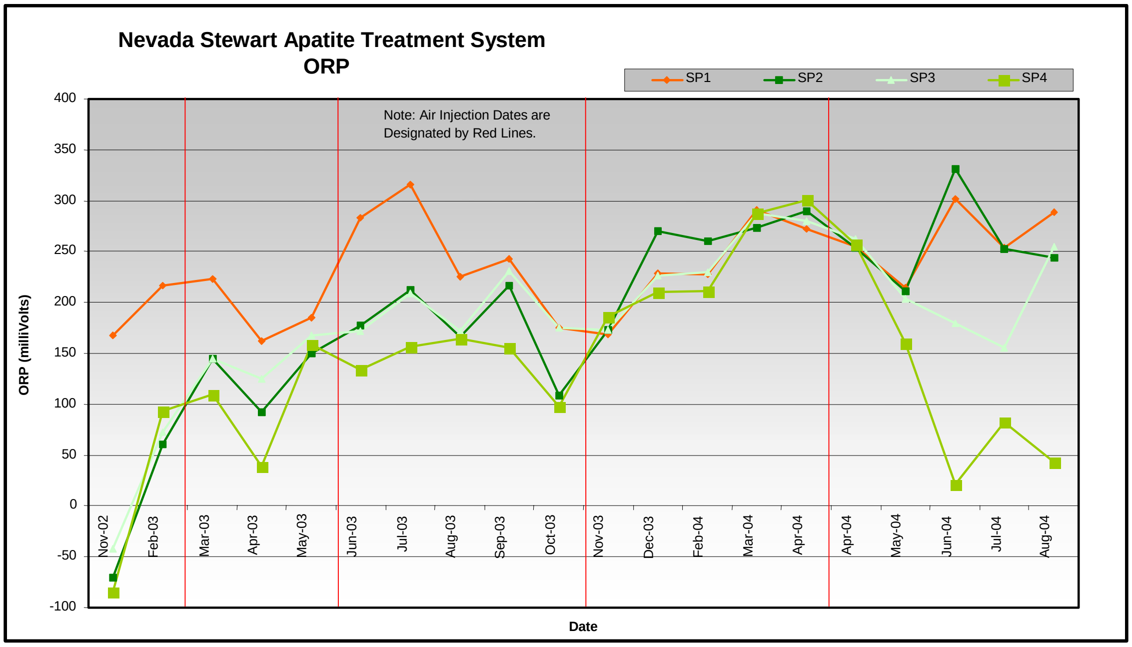


Figure 4-8. NSM ATS ORP.

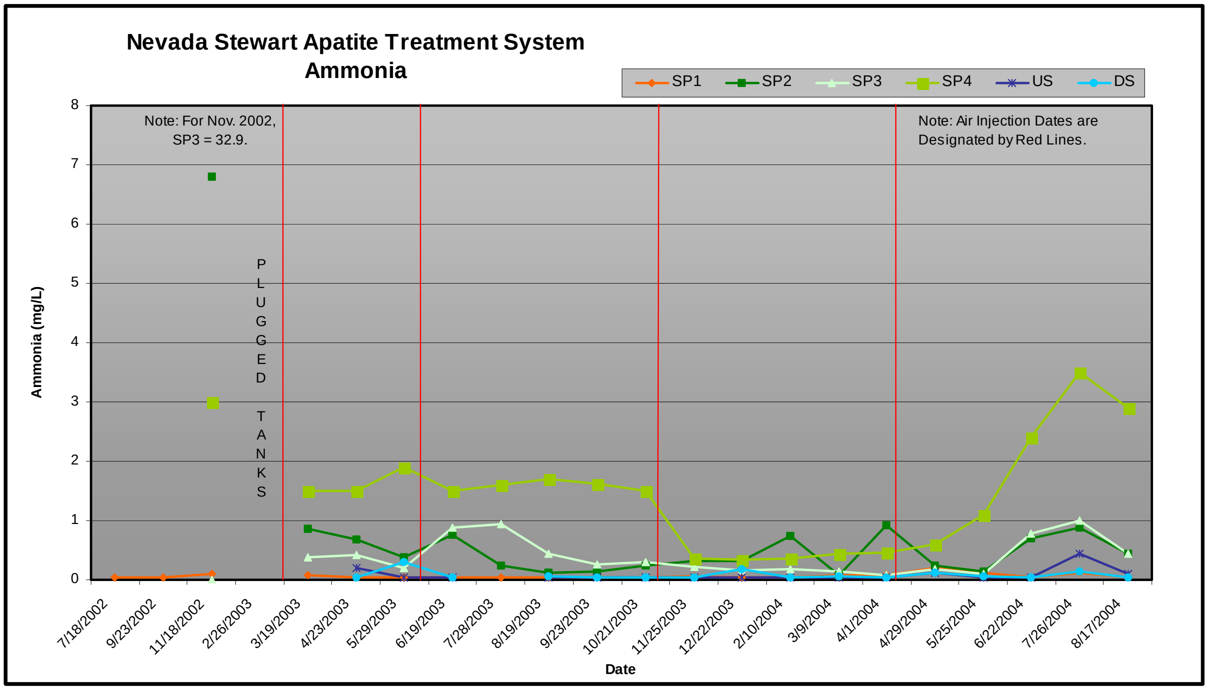


Figure 4-9. NSM ATS ammonia.

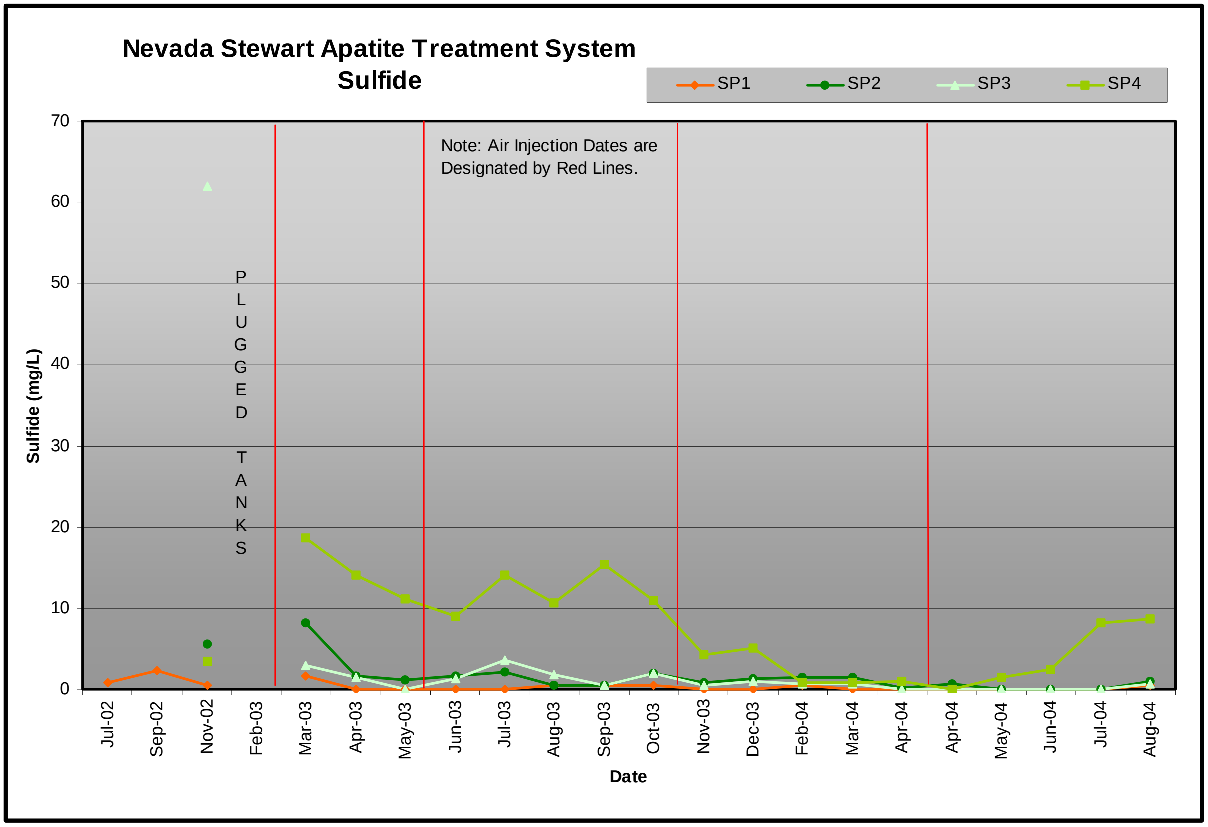


Figure 4-10. NSM ATS sulfide.

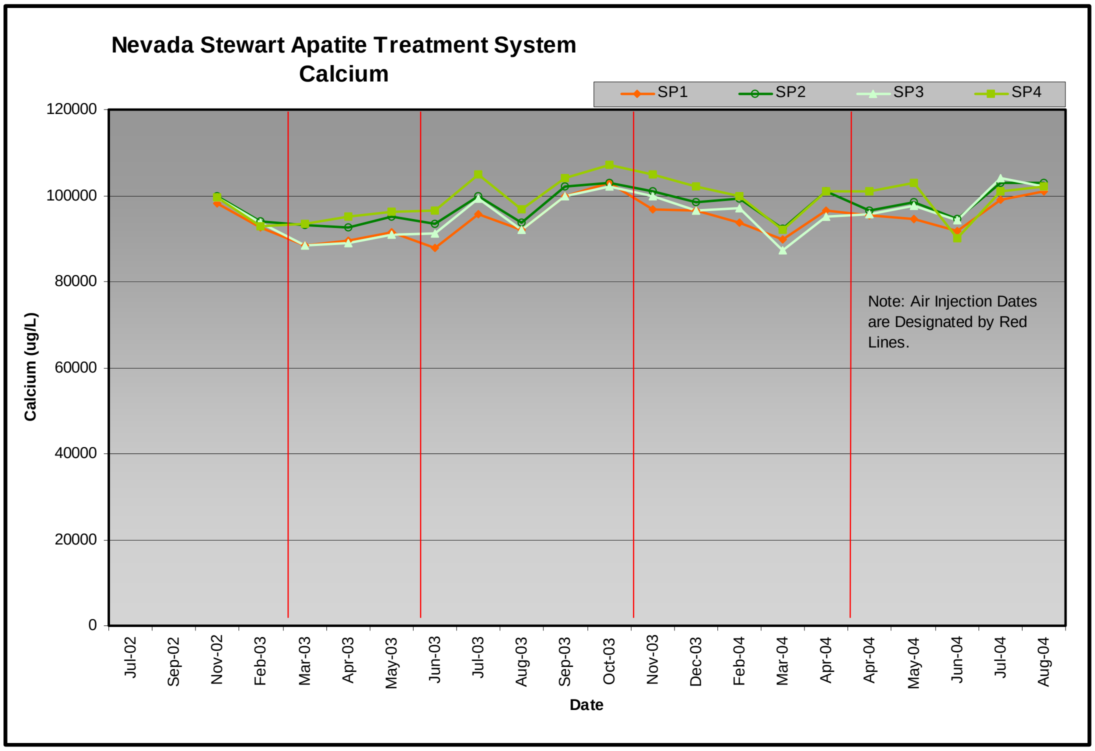


Figure 4-11. NSM ATS Ca.

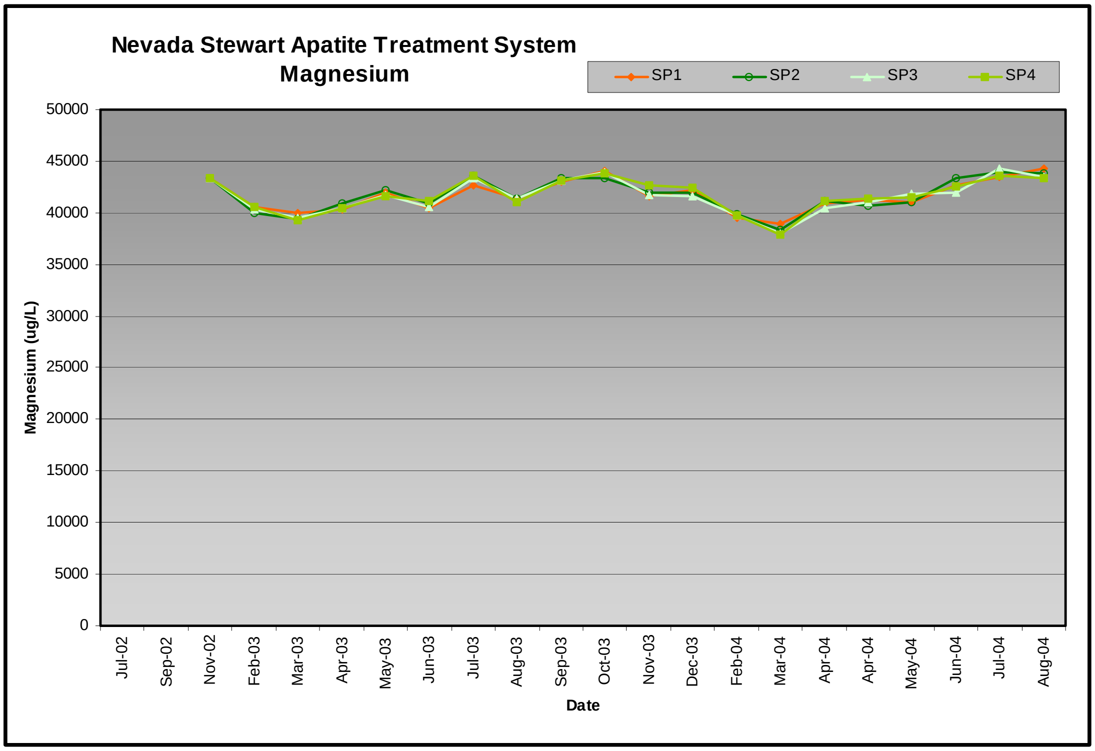


Figure 4-12. NSM ATS Mg.

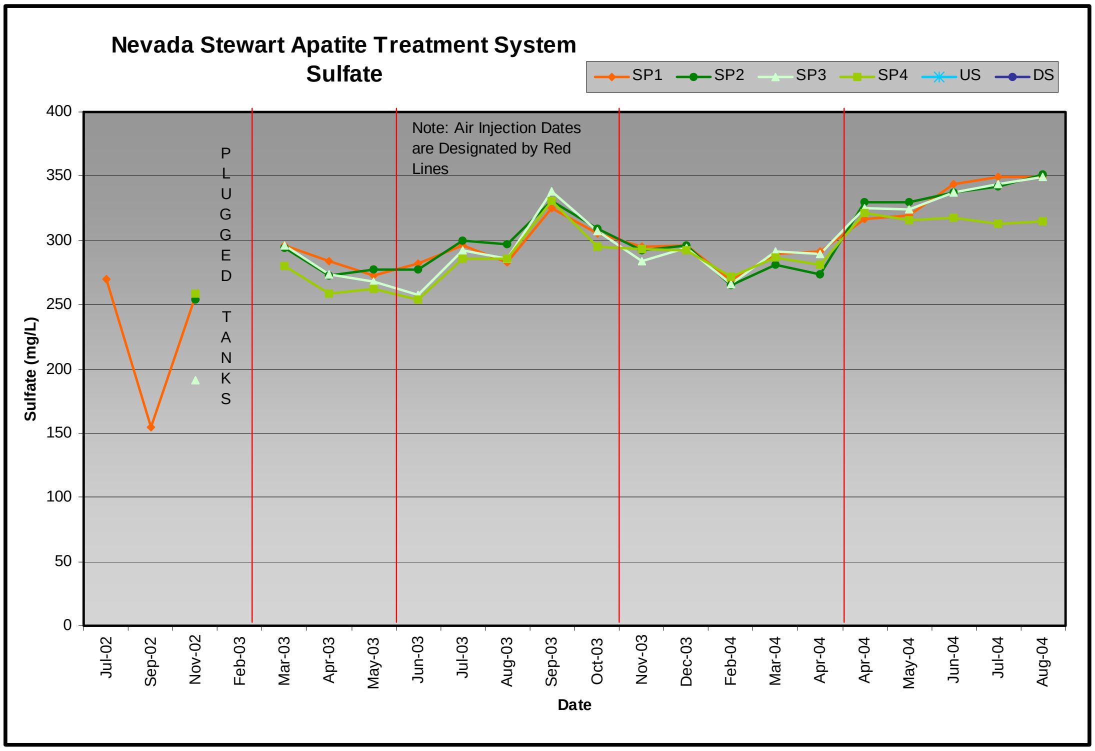


Figure 4-13. NSM ATS sulfate.

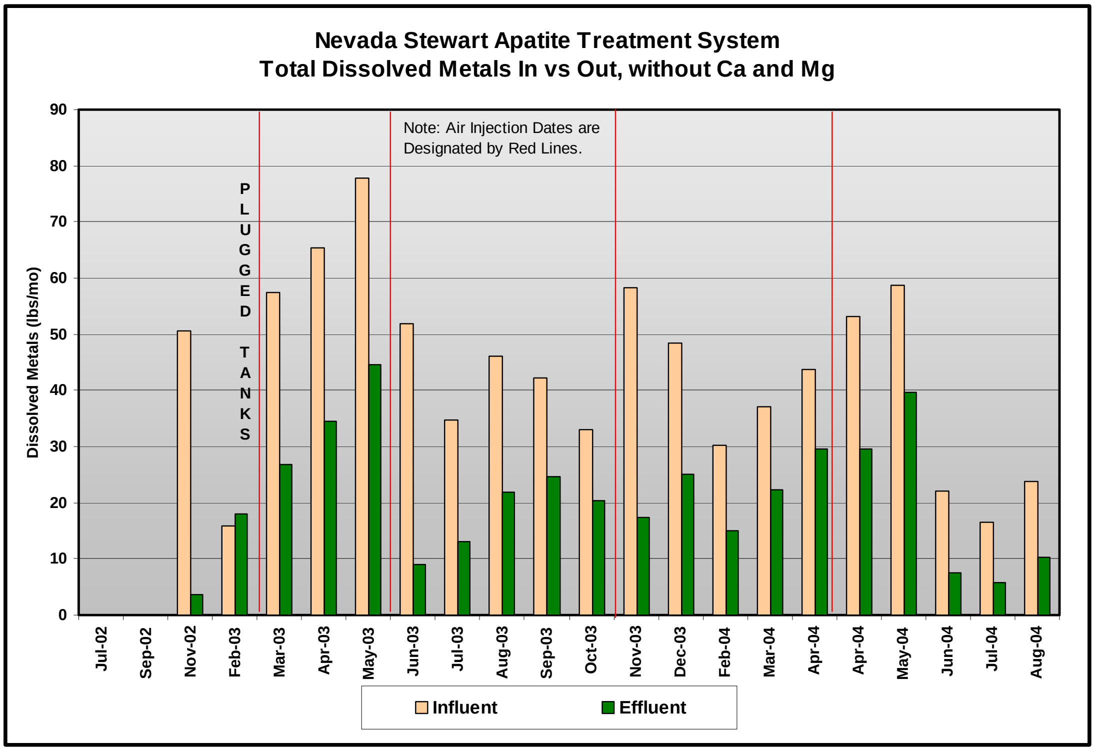


Figure 4-14. NSM ATS total dissolved metals, in versus out, without Ca and Mg.

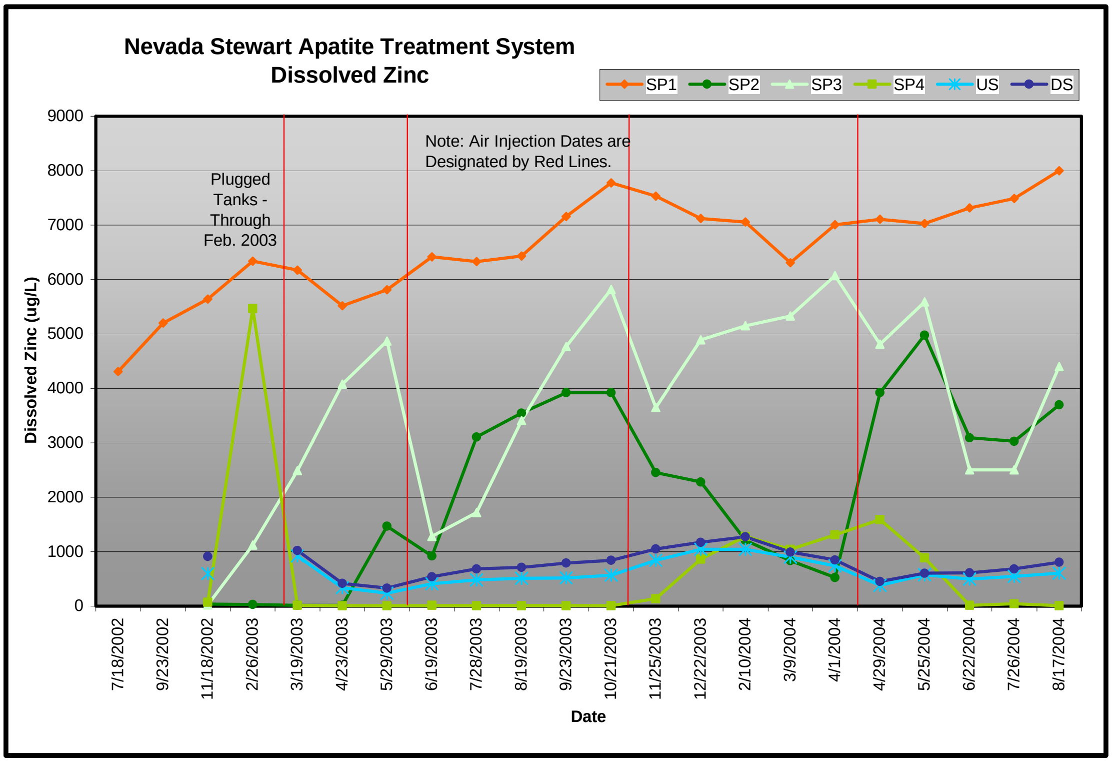


Figure 4-15. NSM ATS dissolved Zn.

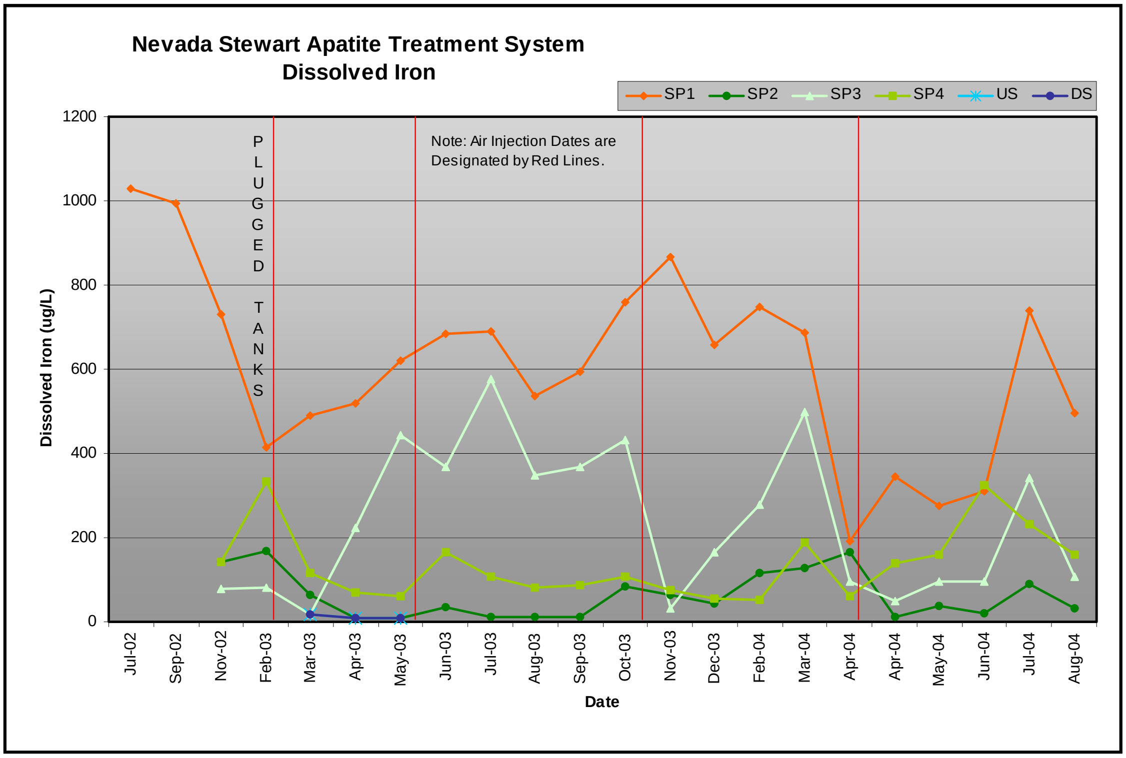


Figure 4-16. NSM ATS dissolved Fe.

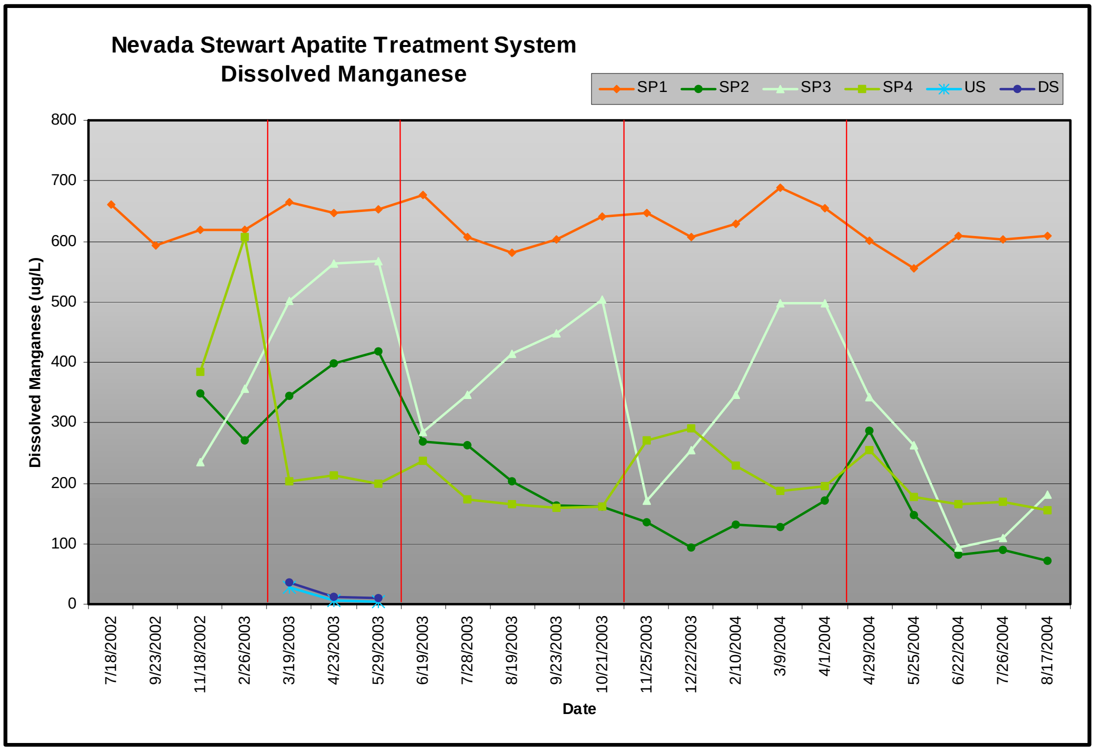


Figure 4-17. NSM ATS dissolved Mn.

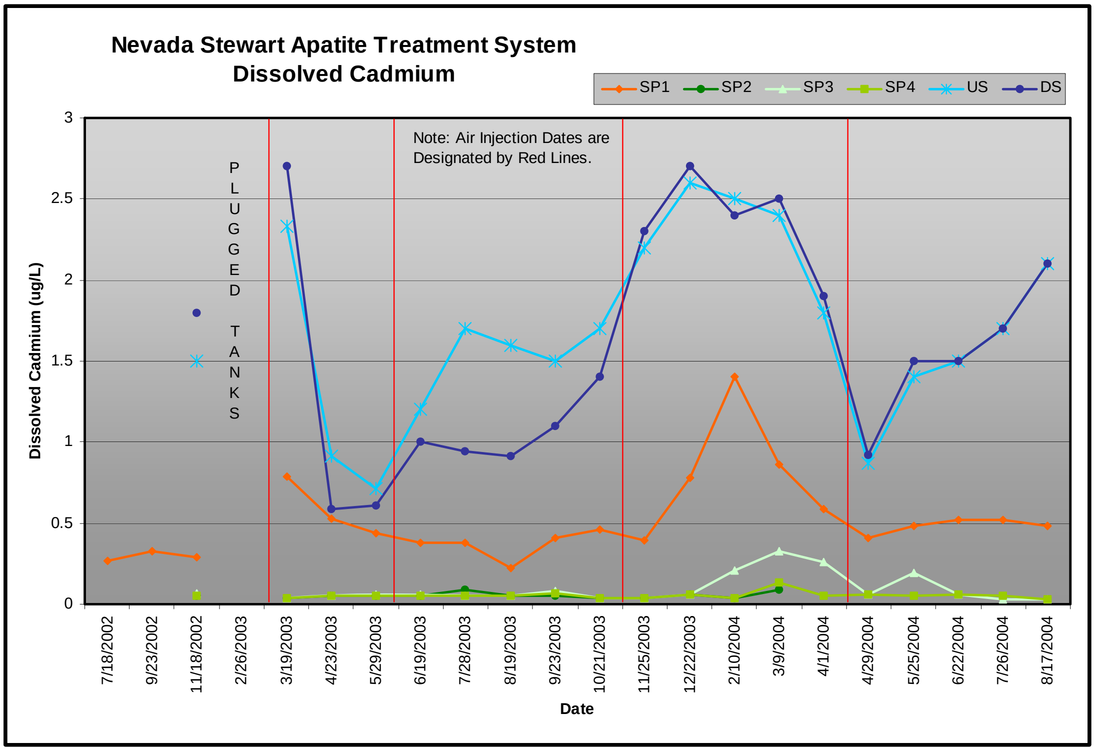


Figure 4-18. NSM ATS dissolved Cd.

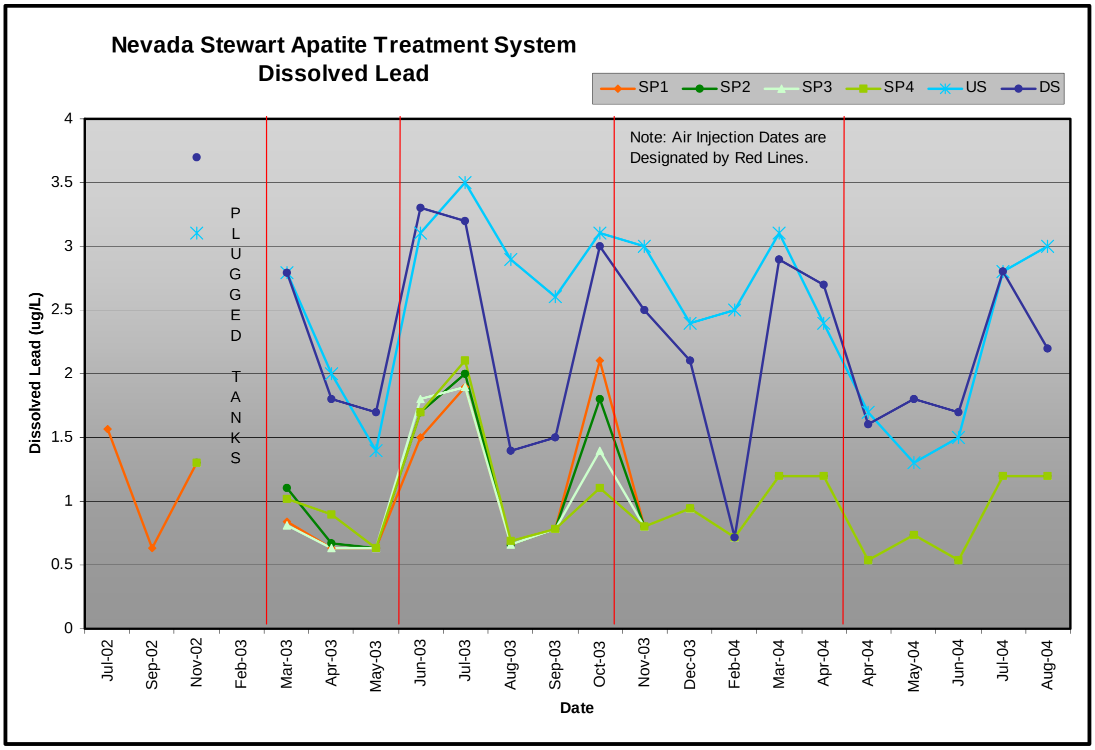


Figure 4-19. NSM ATS dissolved Pb.

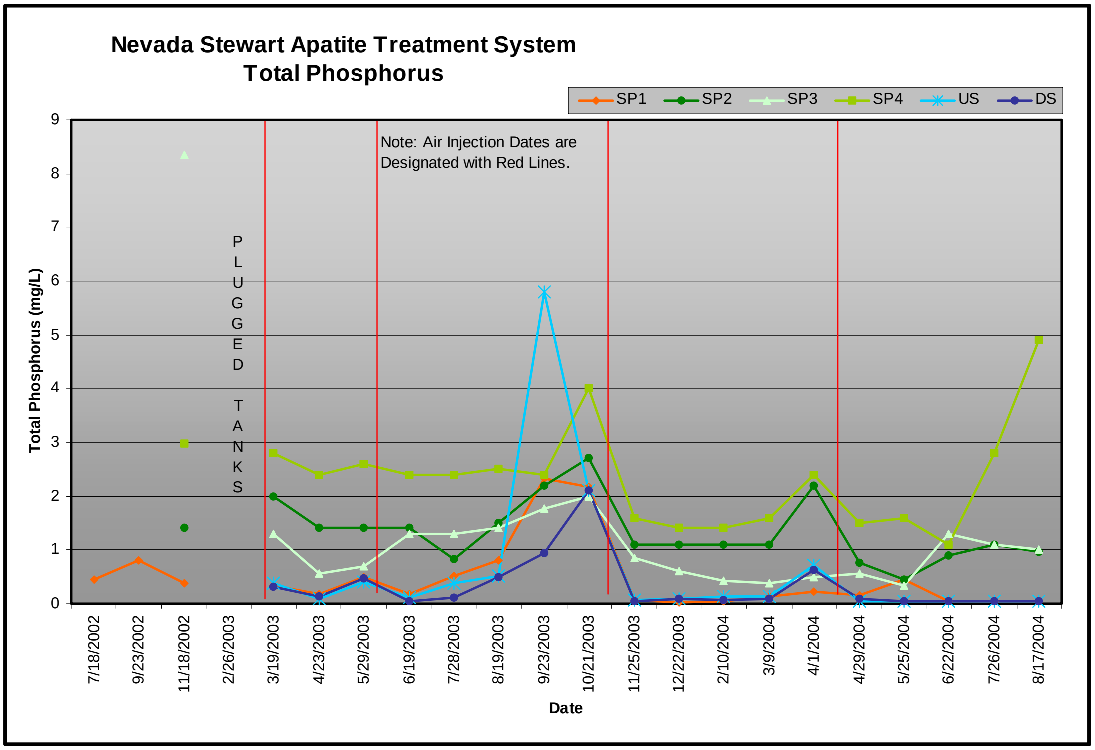


Figure 4-20. NSM ATS total P.

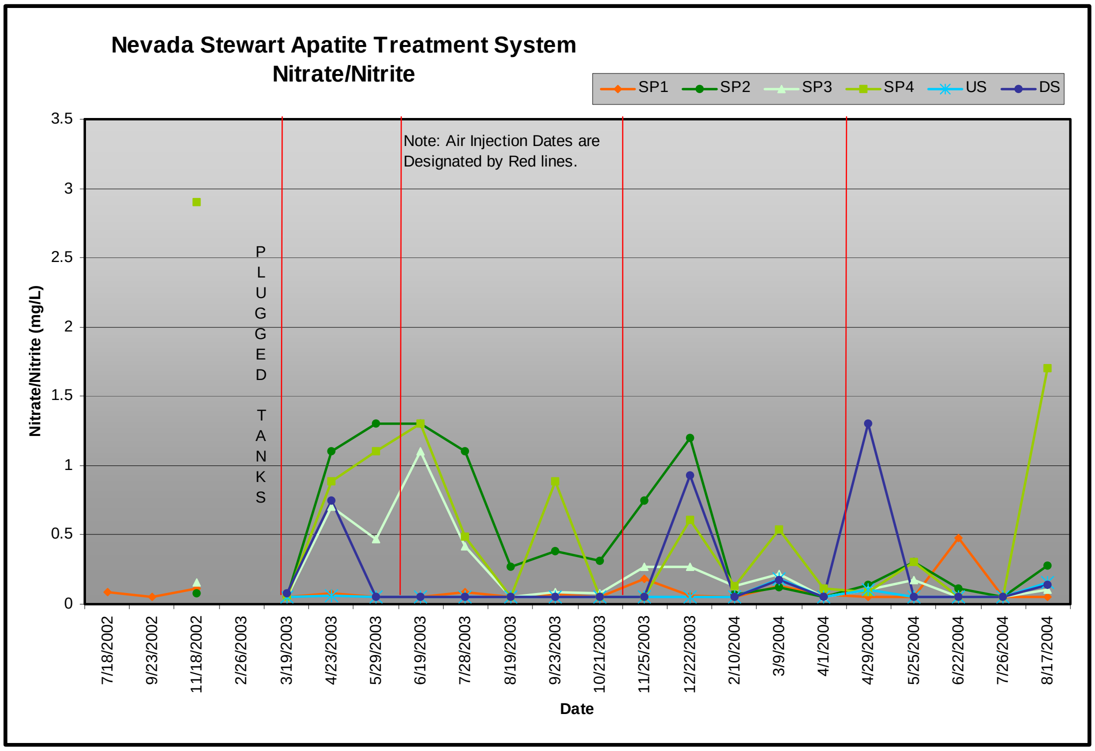


Figure 4-21. NSM ATS nitrate/nitrite.

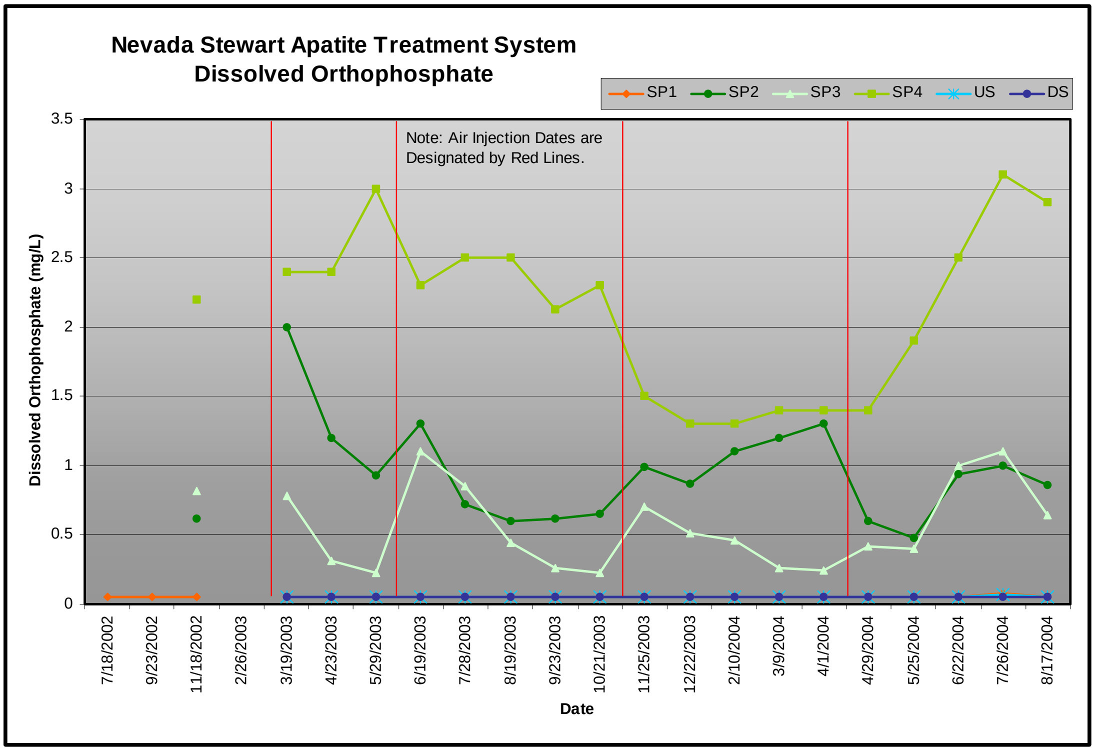


Figure 4-22. NSM ATS dissolved orthophosphate.

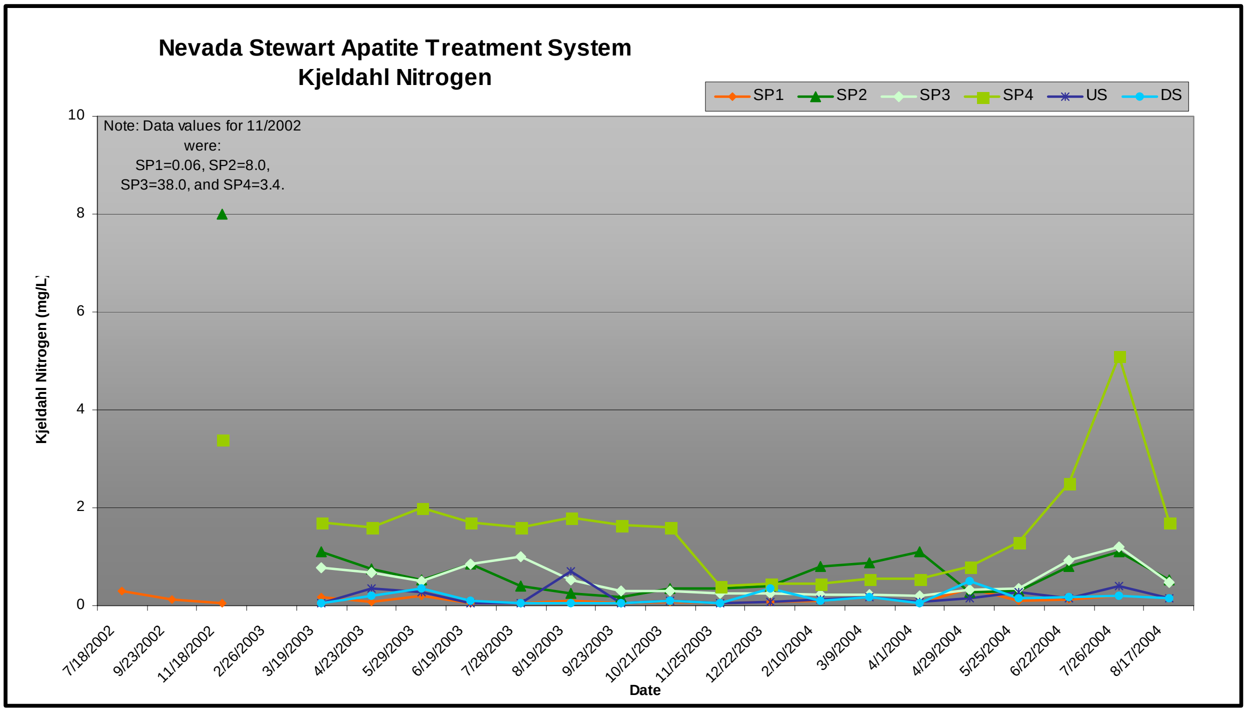


Figure 4-23. NSM ATS Kjeldahl nitrogen.

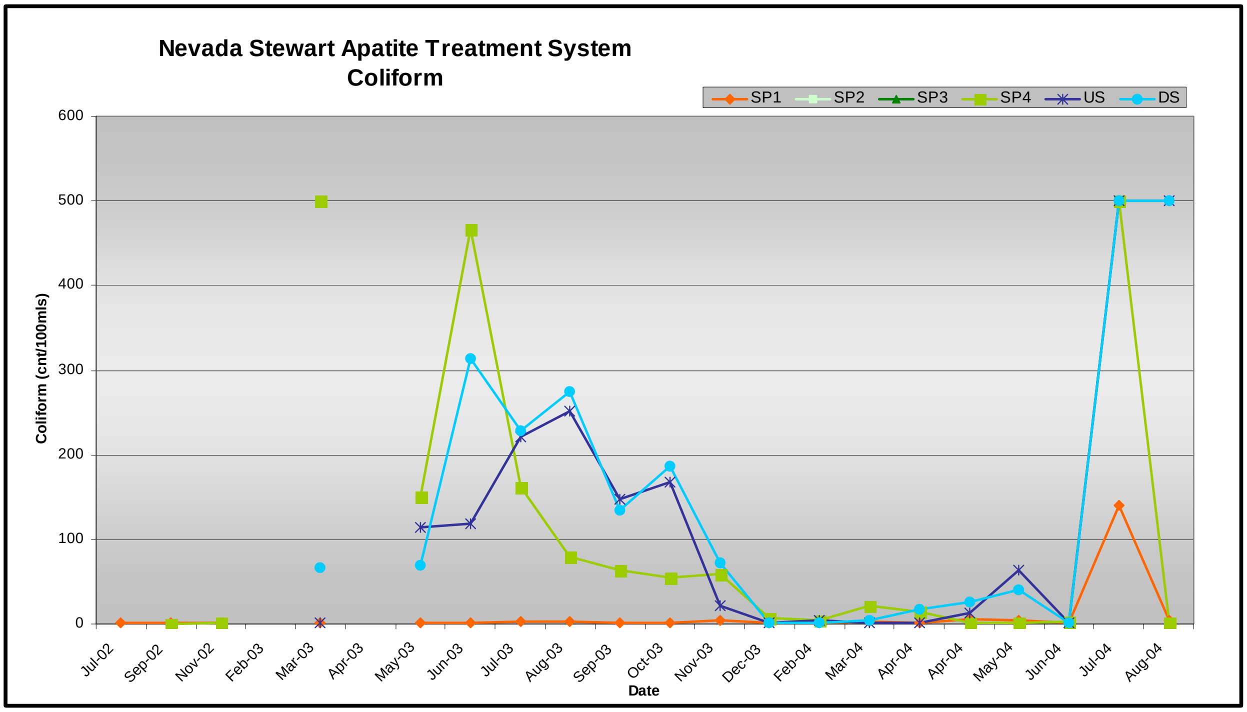


Figure 4-24. NSM ATS coliform.

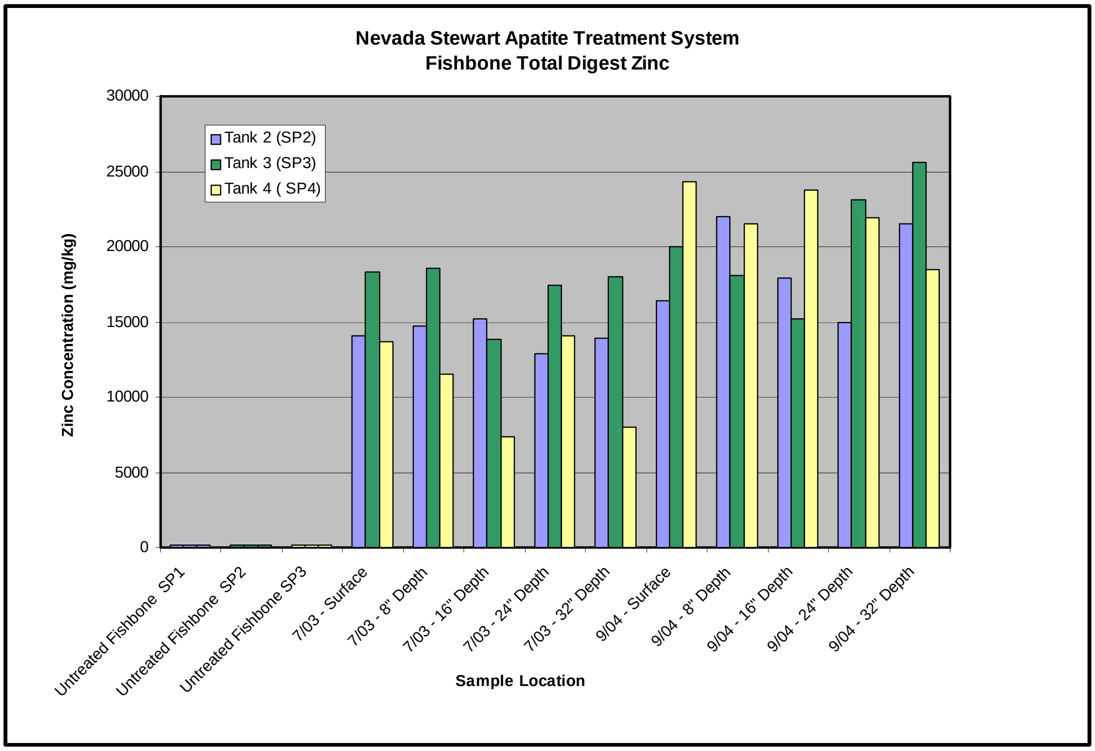


Figure 4-25. NSM ATS total digest Zn.

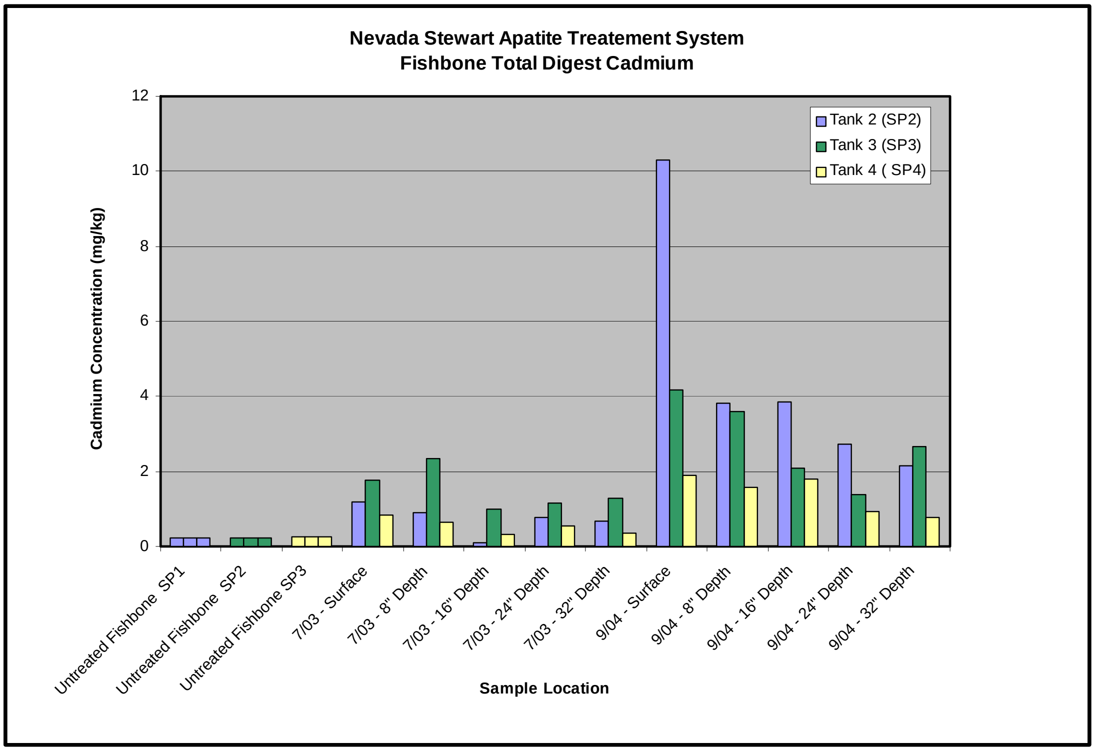


Figure 4-26. NSM ATS total digest Cd.

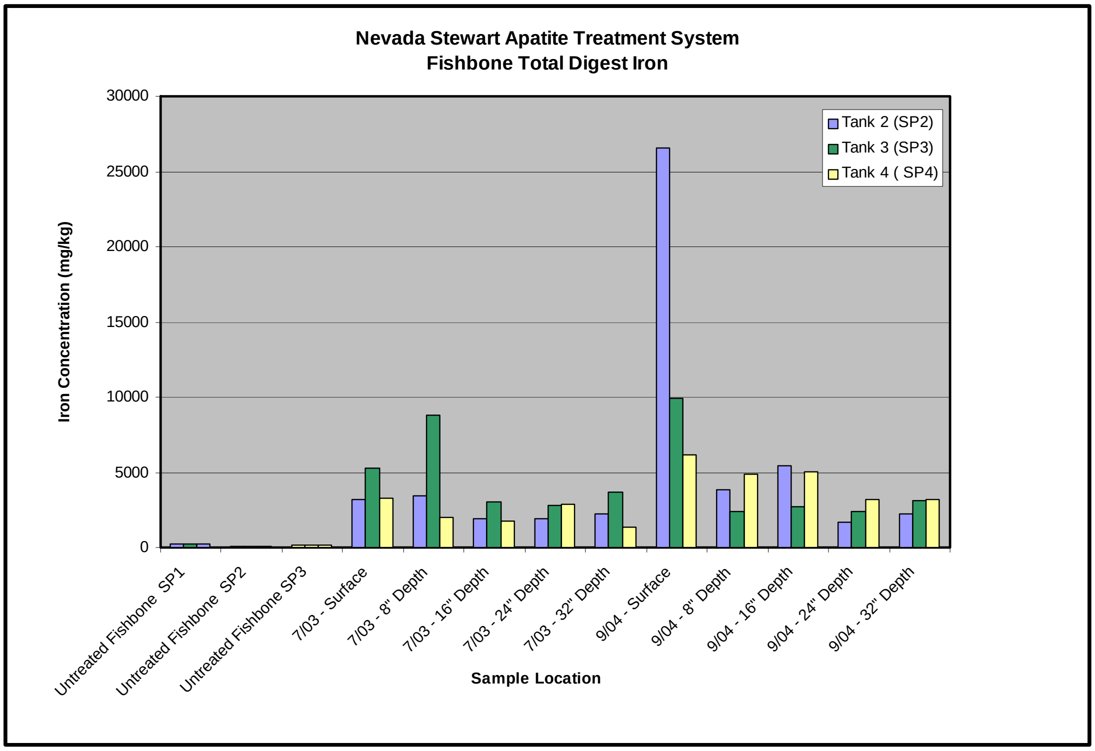


Figure 4-27. NSM ATS total digest Pb.

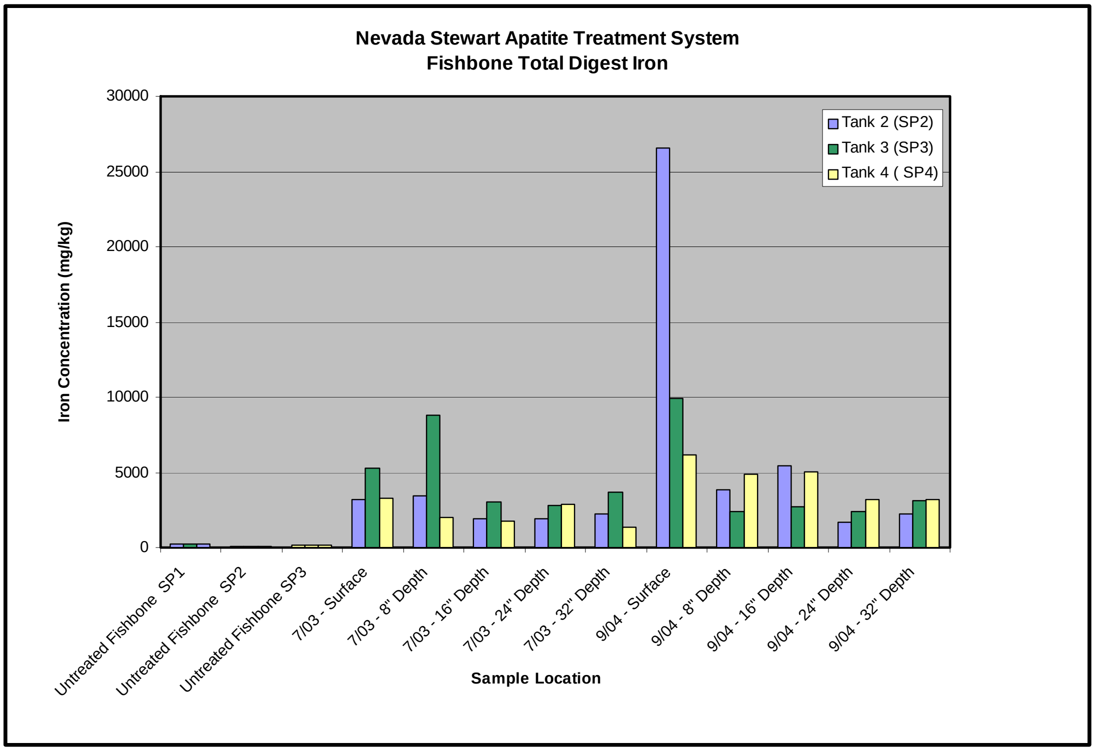


Figure 4-28. NSM ATS total digest Fe.

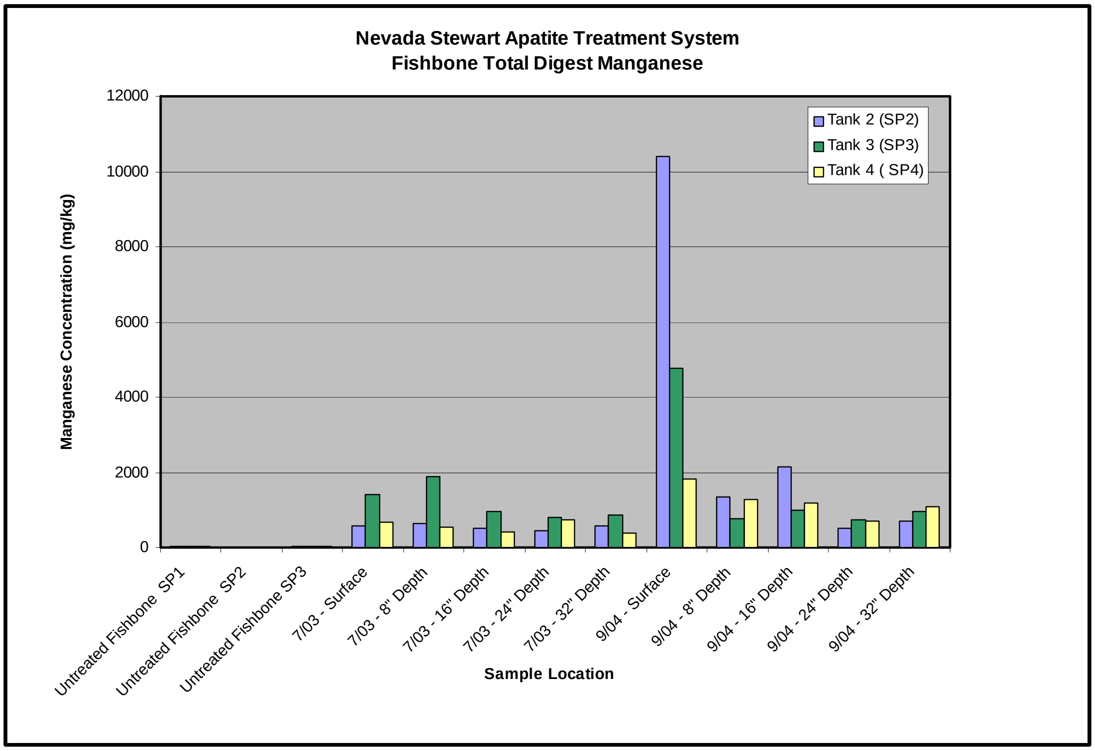


Figure 4-29. NSM ATS total digest Mn.

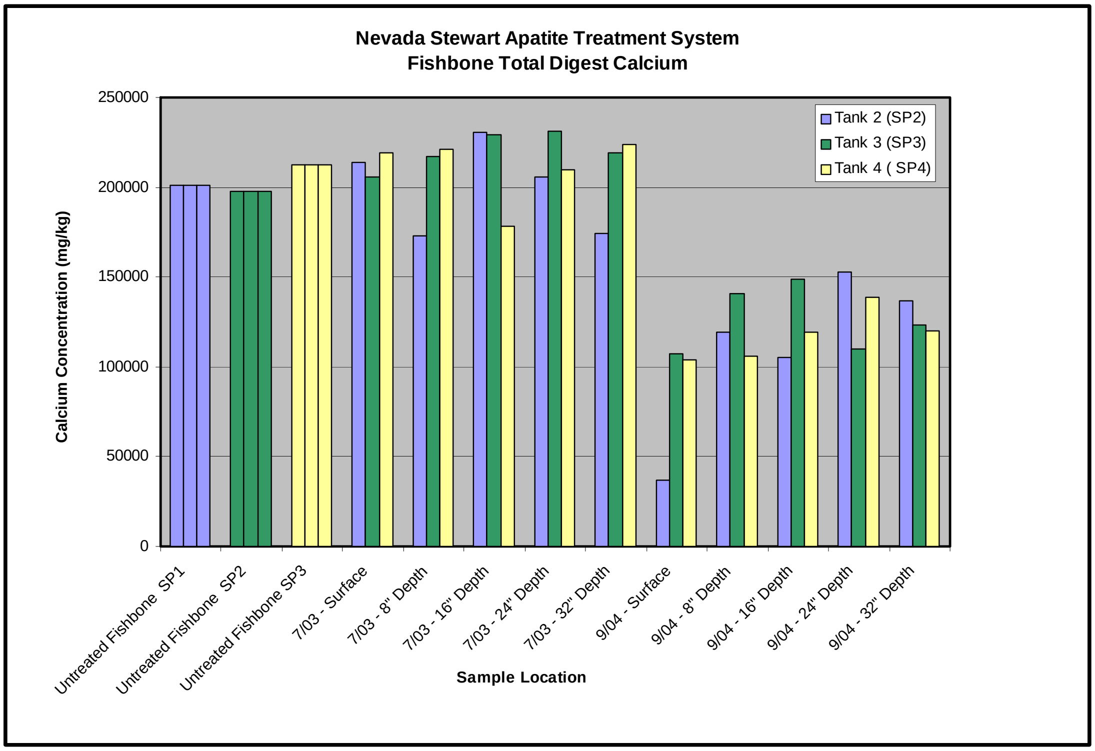


Figure 4-30. NSM ATS total digest Ca.

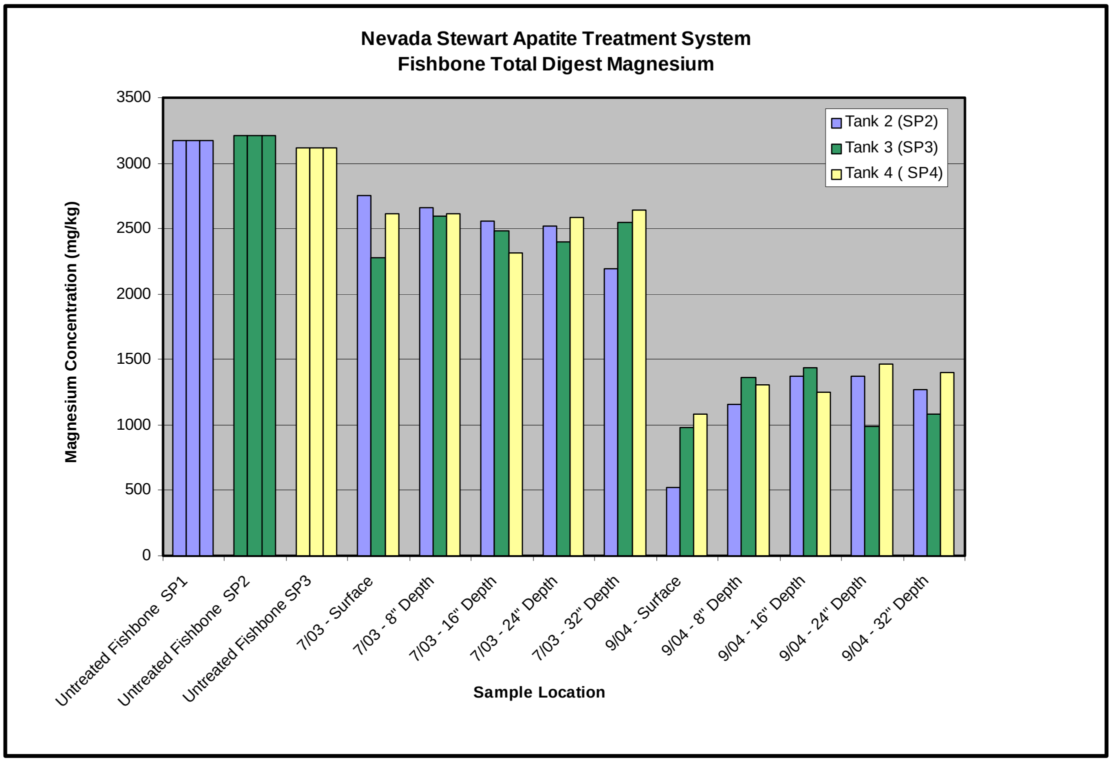


Figure 4-31. NSM ATS total digest Mg.

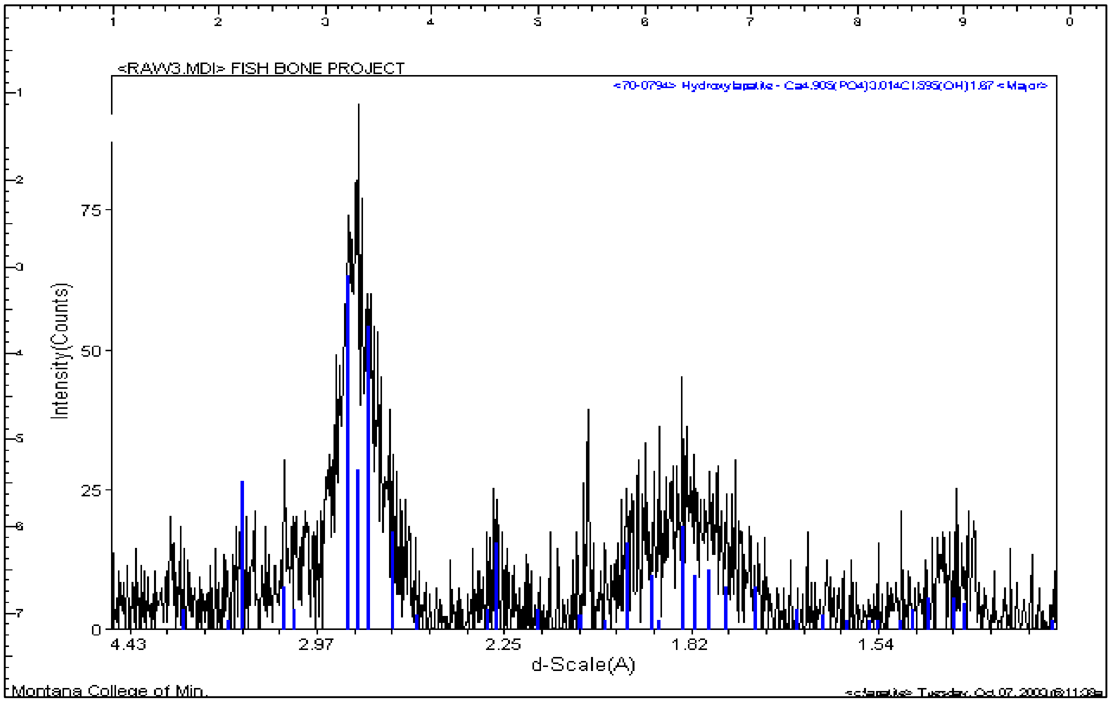


Figure 4-32. XRD graph showing a hydroxyapatite (>70 counts) peak, illustrating the only crystalline structure detected in the raw fishbone sample. This graph was similar to XRD results from Tanks 2, 3, and 4.

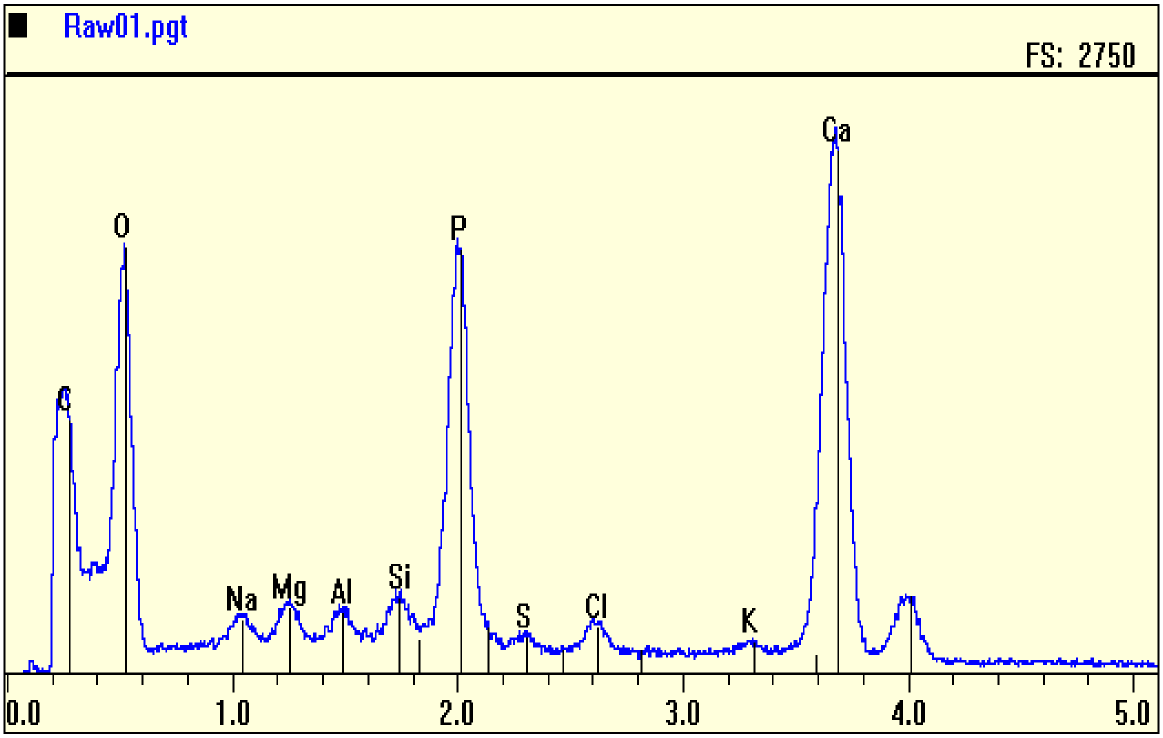


Figure 4-33. Unreacted fishbone EDX scan illustrating the peaks that indicate the primary composition of the fishbone material.

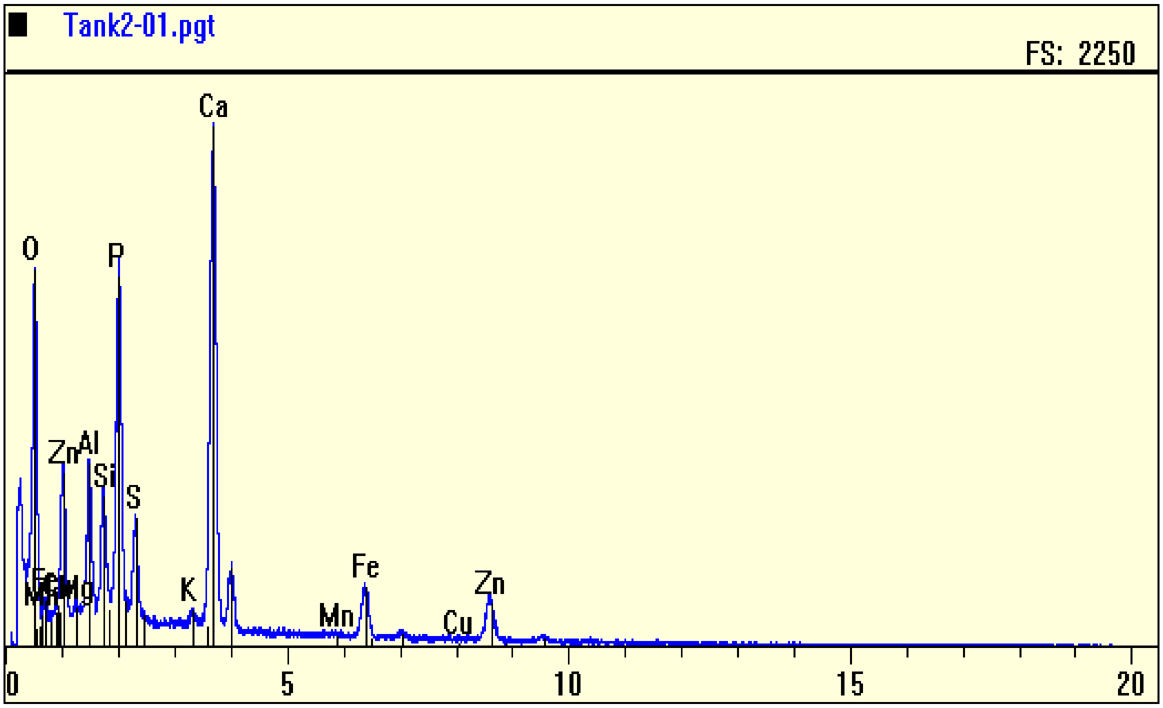


Figure 4-34. Typical EDX scan for Tank 2 (July 2003) sampled after 1 year of treating NSM discharge water. Volume treated by July 2003 was approximately 2 million gallons.

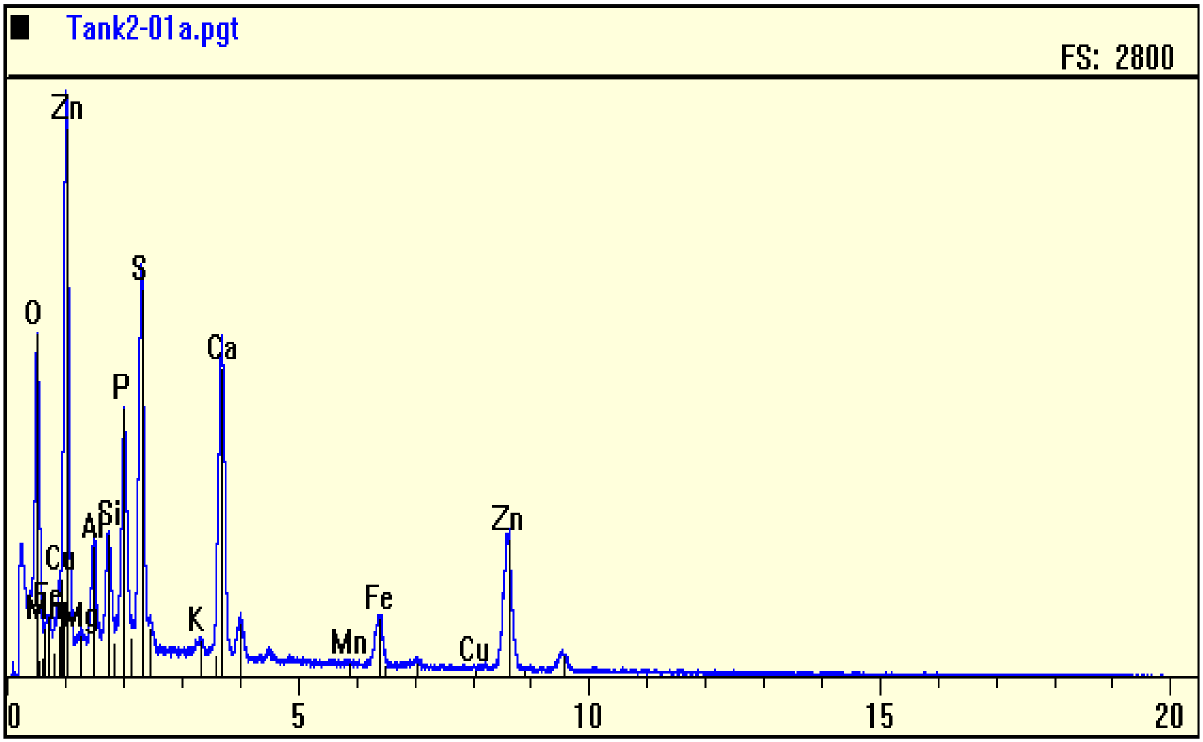


Figure 4-35. EDX scan of bright spot from a sample taken from Tank 2.

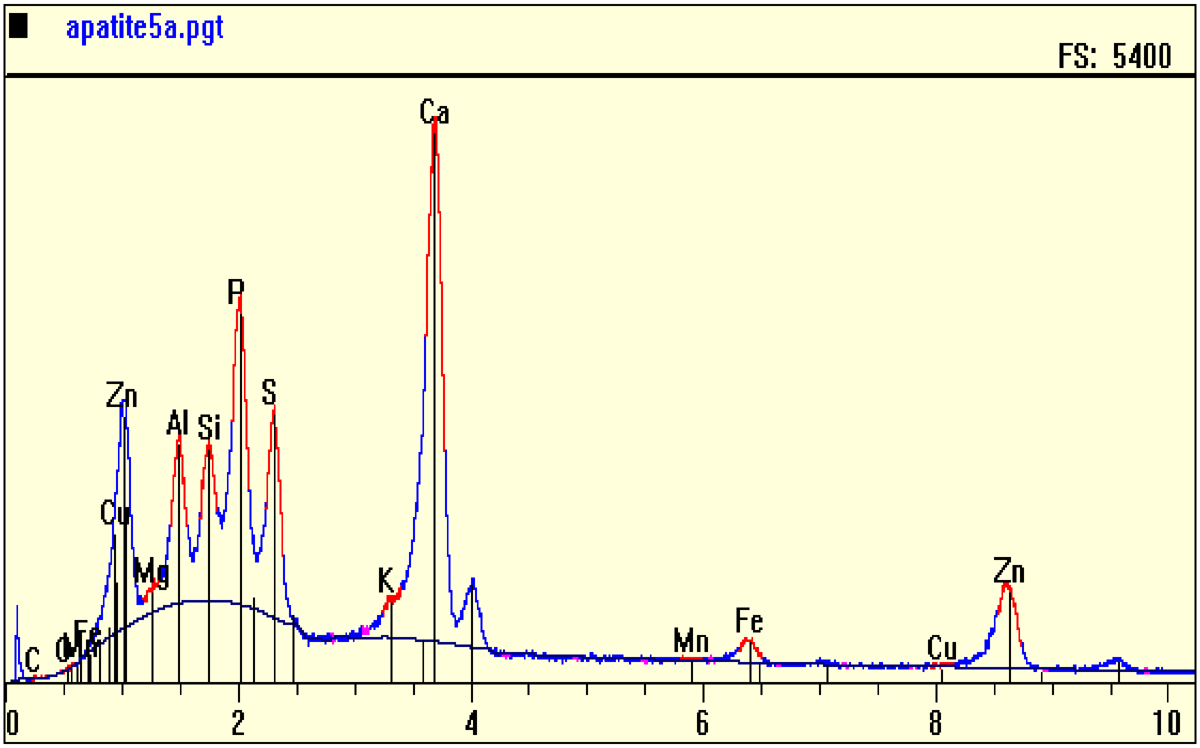


Figure 4-36. EDX scan of entire bone from a sample collected from Tank 4 in July 2003.

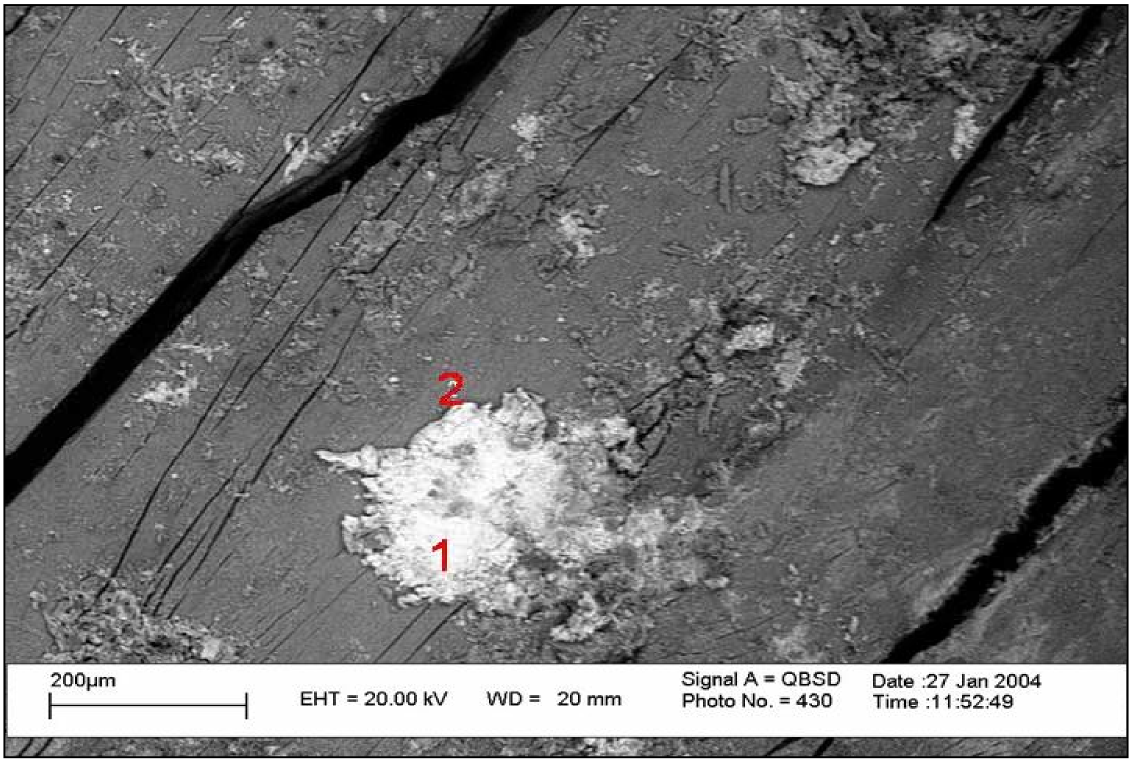


Figure 4-37. Bright regions (1) and dark regions (2).

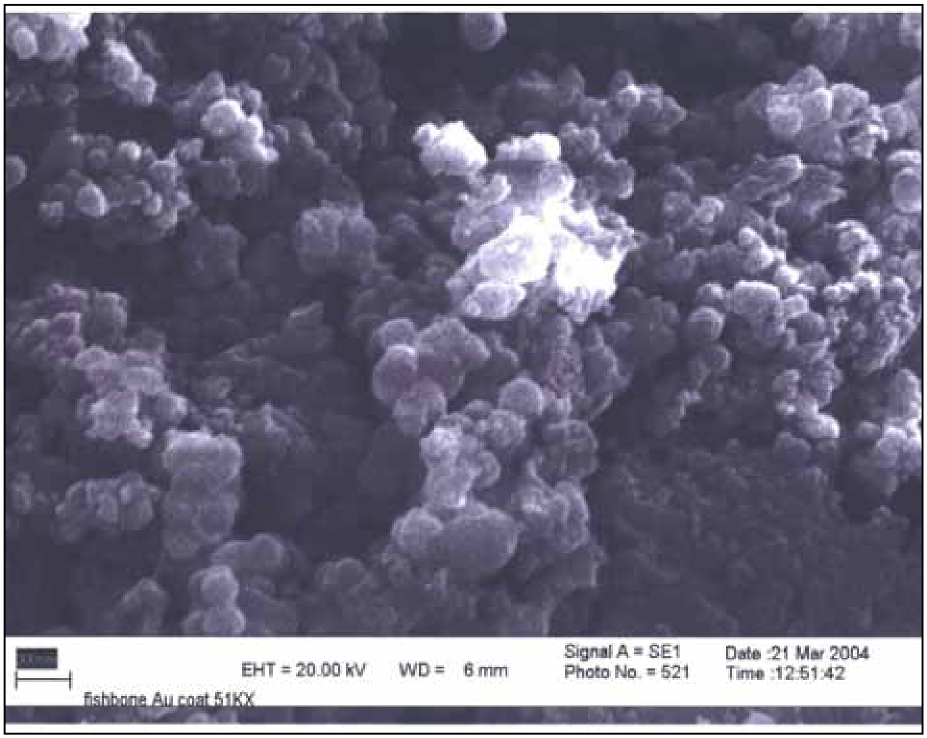


Figure 4-38. Fishbone under high vacuum using SEM to see ZnS crystals from samples collected from Treatment Tank 4 at the NSM ATS.

Table 4-1. NSM ATS Average Volumetric Flow in Gallons Per Minute

Sampling Port Measured	Average Flow Through the System (gpm)	Total Flow Through Each Tank over 2-Year Monitoring Period (million gallons)
SP1 – Influent Flow at Tank 1	17.9	13.4
SP2 – Effluent Flow at Tank 2	5.9	4.5
SP3 – Effluent Flow at Tank 3	8.7	6.4
SP4 – Effluent Flow at Tank 4	3.3	2.5

Table 4-2. NSM SRB Analysis – September 2004

	Tank 1 (SP1) Influent	**Tank 2 (SP2) Effluent**	**Tank 3 (SP3) Effluent**	**Tank 4 (SP4) Effluent**	**Tank 4 (SP4) Effluent Duplicate**
SRB (MPN/mL) – Date: 9/28/2004	<1.8	20	<1.8	78	45
Sulfide (mg/L) – Date: 8/17/2004	0.5	0.95	0.59	8.6	---

Table 4-3. Net Increase and Decline in Concentration as Indicated by Water Quality Monitoring Results

Net Increase in Concentration (Treatment Cell = Source)	**Net Decline in Concentration (Treatment Cell = Sink)**
Ca	Fe
P	Mn
Nitrogen	Zn
	Al[1]

[1] Al was taken only on an annual basis. Other metals were sampled on a monthly basis.

Table 4-4. Saturation Indices for the NSM ATS Influent and Each Separate Effluent Flow for the System (Results are from the Last Sampling Event taken on August 17, 2004, after System had Functioned for a 22-Month Duration)

Saturation Indices for the NSM ATS Influent and Each Effluent*				
Mineral Phase	**Influent Flow**	**Effluent Flow**		
	SP1	**SP2**	**SP3**	**SP4**
Ferrihydrite	1.1	-0.6	-0.1	-3.6
Mackinawite	-2.8	-3.5	-3.2	0.1
Pyrite	21.1	19.2	19.6	19.3
$MnHPO_4$	1.3	1.4	1.6	2.5
Hydroxyapatite	-0.7	2.9	1.9	5.4
Sphalerite	6.3	6.3	6.2	1.0
Wurtzite	4.3	4.3	4.1	1.0

***** The geochemical results presented are from sampling event on August 17, 2004, and not the other dates for the project.

Table 4-5. Weight Percent Data from EDX Scan for Sample Collected from Tank 4 in July 2003

Element	Wt%	Atomic Weight Percent (At%)
C	0.00	0.00
O	0.00	0.00
Mg	1.75	2.62
Al	7.67	10.35
Si	6.44	8.34
P	22.51	26.44
S	12.75	14.46
K	2.90	2.70
Ca	26.41	23.98
Mn	0.21	0.14
Fe	2.10	1.36
Cu	0.37	0.21
Zn	16.90	9.40
Total	**100.00**	**100.00**

Table 4-6. Weight Percent Data from Bright Region and Dark Region Located on Fishbone Material from Treatment Tank 4 Compared to Data from Sample of Untreated (Raw) Fishbone Material

Element	Bright Region		Dark Region		Raw Fishbone[a]	
	Wt%	At%	Wt%	At%	Wt%	At%
O	25.68	49.16	62.31	79.65	72.84	85.06
Mg	0.21	0.26	0.00	0.00	1.11	0.86
Al	4.42	5.02	2.53	1.92	2.13	1.48
Si	0.88	0.96	0.54	0.39	1.43	0.95
P	3.78	3.73	7.84	5.18	9.00	5.43
S	17.38	16.60	4.79	3.05	0.18	0.11
K	0.00	0.00	0.00	0.00	0.62	0.30
Ca	6.06	4.63	14.55	7.42	12.11	5.64
Mn	0.34	0.19	0.20	0.07	0.00	0.00
Fe	0.80	0.44	0.67	0.25	0.34	0.11
Cu	3.93	1.90	0.63	0.20	0.12	0.03
Zn	36.52	17.11	5.96	1.87	0.11	0.03
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.0**	**100.0**

[a] EDX analysis of Figure 4-33.

Table 4-7. Solubility Products

Metal Sulfide	Formation	Log K
CdS (Greenockite)	$CdS + H^+ \leftrightarrow Cd^{2+} + HS^-$	-15.93
PbS (Galena)	$PbS + H^+ \leftrightarrow Pb^{2+} + HS^-$	-12.78
ZnS (Sphalerite)	$ZnS + H^+ \leftrightarrow Zn^{2+} + HS^-$	-11.62

Source: Drever 1997

Table 4-8. 2003 Versus 2004 LC50 Values

	2003		2004	
	C. dubia	***P. promelas***	***C. dubia***	***P. promelas***
SP1	2.21	26.39	2.19	9.29
SP2	4.07	70.71	6.27	25.46
SP3	5.83	90*	4.42	6.93
SP4	95% *	100%*	85% *	89.09

* Indicates percent survival in 100%, non-diluted sample (no LC50 values could be generated)

5. ATS Monitoring Results Evaluation

In the QAPP for this project, the primary objective was to determine the percent reduction of metals for the target constituents by measuring total and dissolved metals concentrations in the ATS influent and effluent.

5.1 Statistical Analysis of the ATS Removal Effectiveness

Project objectives, design information, and data were provided to EPA, and an EPA contractor statistician reviewed the data. Only the representative target analytes listed in the project QAPP were evaluated (Ref. 1).

Statistical data analyses (both descriptive and inferential) were performed for total Zn, Cd, Pb, Fe, Mn, Ca, and Mg. This information is summarized as listed below.

- Descriptive Statistics: Minimum, Median, Maximum, Mean, Standard Deviation (Section 5.1.1).
- Inferential Statistics: Kruskal-Wallis Test and Multiple Comparison Procedure (Section 5.1.1).
- Graphical Displays: Box Plots (Appendix F).
- Graphical Displays: Time Plots (Appendix F).
- How to Interpret Box Plots (Appendix F).

5.1.1 Exploratory Data Analysis

Percent reduction for seven target metals was used to construct Tables 5-1 through 5-7, and the box plots are provided in Appendix F. The percent reduction using total metals concentrations was calculated as

[(SP1 Metal Concentration - SP # Metal Concentration) / SP1 Metal Concentration] x 100

Data collected for February 2003 was not representative of flow-through conditions at the ATS and should not be compared to other data that do represent flow through conditions.

For Zn, the box plots show a high (> 80%) reduction for Tank 4 at SP4. Time plots indicated the reduction was independent of the influent concentration (see Appendix F box plots for Zn), which almost doubled over the duration of the project (Figure 4-15). Over the duration of the project, Tanks 2 and 3 on average showed more modest reductions (20% to 70%) where the reduction was considered to be a function of the influent concentration. The results from the Kruskal-Wallis testing for Zn were statistically significant (p-value < 0.002) (Table 5-8). The Kruskal-Wallis multiple comparison procedure indicated that the Zn reduction at each sampling port (i.e., treatment tanks) was statistically different from one another (p-value = 0.05) (Table 5-8). This is reflective of the variability between treatment tanks throughout the duration of the project, with respect to flow rates and associated residence time, metals concentrations, and measured physical parameters.

Concentrations for Cd and Pb were very low in the influent resulting in below laboratory instrument detection limits (IDLs) for several months. Even so, the average percent reduction was evaluated for the two metals. The Cd box plots showed a high (> 75%) reduction for Treatment Tanks 2 and 4 (Appendix F). Evaluation of the time plots indicated the reduction was independent of the influent concentration. This did not hold for Tank 3, where the reduction in loading was a function of the influent concentration. Time plots are provided in Figure 4 of Appendix F, where the time plots indicate that Tank 3 was not removing Cd in a similar manner as Tanks 2 and 4. This observation was confirmed with the Kruskal-Wallis test (Table 5-9). The result of the Kruskal-Wallis test was statistically significant (p-value < 0.002). The Kruskal-Wallis multiple comparison procedure indicated that Tanks 2 and 4 were statistically different from Tank 3 (p-value = 0.05), thus, confirming the evaluation from the time plots and the geochemical results.

The Pb box plots showed a similar reduction for all three sampling ports (20% to 80%) (Appendix F, Figure 2). The time plots in Appendix F, Figure 5 indicate the reduction was independent of the influent concentration for Tanks 2 and 4. This does not hold for Tank 3, where the reduction was determined to be a function of high influent concentrations. The result of the Kruskal-Wallis test was statistically significant (Table 5-10). The Kruskal-Wallis multiple comparison procedure indicated that Tanks 2 and 3 were statistically different (p-value = 0.05) than results from Tank 4.

In an additional statistical analysis, Fe, Mn, Ca, and Mg concentrations and load reductions were evaluated. The reviewed data did not have any outlying reductions for the metals (Appendix F, Figures 1-4). Neither Ca nor Mg concentrations were reduced by the treatments (Tables 5-6. 5-7. 5-11, 5-12, and Appendix F, Figures 3, 4, 7, and 9). In fact, Ca and Mg were released into solution as depicted by the geochemical modeling and were not evaluated further.

For the two remaining metals, Fe and Mn, SP2 provided the greatest reduction at 95.6% and 67.82%, respectively (Tables 5-4 and 5-5). The Kruskal-Wallis tests for both metals were statistically significant (p-value < 0.002), as were all treatment differences (p-value = 0.05) (Tables 5-13 and 5-14). For both metals, as reflected by the statistical analysis, SP3 was the worst performer having the smallest percent reduction and largest variability. There was a slight negative correlation between initial and final concentrations for both metals for SP3, where Fe = 0.32 and Mn = 0.55 and for SP2, where Fe = 0.25 and Mn = 0.41. This trend was positive for SP4, where Fe = 0.67 and Mn = 0.01. However, over the duration of the project, Tank 3 treated an increased amount of influent through the ATS (49% of the flow) and had reduced retention times, which were not accounted for in the calculations for the average percent metal reduction.

5.2 Water Quality Monitoring Evaluation

5.2.1 Percent Reduction of Metals at the NSM

The average percent reduction of dissolved metals and total metals for the ATS system was determined to evaluate the effectiveness of the ATS for metals removal from solution (Table 5-15).

As illustrated in Figure 5-1, the average percent metals reduction of dissolved metals achieved by the ATS was greater than 50% for the 2-year duration of the project for Cd, Fe, Mn, and Zn. The percent reduction for Cd and Fe was as high as 85% and 72%, respectively. For Zn, Tank 4 provided the highest average percent reduction of 94.5%, where Tank 3 average percent reduction was only 40%. However, upon evaluation, Tank 4 treated only one-third of the volume of influent when compared to the other treatment tanks, and the total digested Zn concentrations and metals loading values from each treatment tank indicate that Tank 3 retained a greater amount of Zn than Tank 4. Most of the Zn was retained in Tank 3 during the first year of the project, even though the average percent reduction recognized for Zn was 40%. The total amount of Zn retained in the ATS was 335 pounds (lb) over the 22-month demonstration period.

Table 5-16 presents a comparison of influent and effluent concentrations to regulatory discharge limits for the first and last sampling events of the project.

5.2.2 Apatite Retained Metals in the ATS

In prior studies, it was recognized that the Apatite II^{TM} technology was successful with stabilizing from 5% to 50% of its weight in metals depending upon the metal and environmental conditions. The 5% value was strictly for adsorption and did not address dissolution/precipitation reactions, etc. (Ref. 8). For the Nevada Stewart ATS, the total weight of the apatite medium in the three treatment tanks was 10,000 lb, meaning that the apatite medium at the NSM had the ability to retain a minimum of 500 lb of metal. After 2 years of functioning, a conservative estimate of the total amount of metal retained by the ATS was calculated at approximately 495 lb (Figure 5-2). Each treatment tank retained different percentages of metals due to the flow variances through each tank on a monthly basis. Figure 4-14 provides a monthly graphical presentation of the total amount of heavy metals removed on a monthly basis when comparing the influent and the effluent   This shows that air sparging the tanks to enhance permeability improved the ATS's ability to remove metals. However, over time, the effect was less due to the exhaustion of the attenuation capacity of the ATS. There appears to be several other processes at work that should be addressed.

Even though Tank 4 maintained the highest removal efficiency for Zn (greater than 90%), its low rate of flow allowed the removal of only 28 lb of Zn from the treated influent. For Zn, Tank 3 maintained an overall removal efficiency of only 40%, but approximately 269 lb of Zn was removed from the influent water treated by Tank 3. This amount of metal exceeded the theoretical adsorption capacity of metal for the Apatite II™ in the treatment tank. The fluctuations in attenuation for Zn are depicted in Figure 5-3 and as detailed, Tank 2 was nearing adsorption metal capacity exhaustion at 5% because it had retained 334 lb Zn and 160 lb Fe and Mn. However, absorption is not the only removal mechanism functioning in the ATS system; therefore, to determine the adsorption capacity of the apatite medium would require further detailed analysis that was not funded within this study.

5.2.3 ATS Attenuation Mechanisms

5.2.3.1 Sulfide Mineral Precipitation

Precipitation of ZnS was determined to be the main mechanism for Zn attenuation within all three of the treatment tanks. This process appeared to have dominated the removal scenario within Tank 4 and, to a lesser effect, in Tank 2 or Tank 3. Additionally, the precipitation of ZnS occurred in Tank 3 at times throughout the project duration.

A minor amount of Fe attenuation within the treatment tanks (in particular Tank 4) may be attributed to the precipitation of FeS. The reducing conditions in the NSM ATS, specifically the presence of hydrogen sulfide, suggests that metal attenuation through sulfide precipitation occurred at the NSM. The Golder thermodynamic modeling also confirmed this. Golder's report is contained in Appendix D. The lowest effluent Zn concentrations occurred in association with elevated sulfide concentrations. Mineralogical evaluation, however, is the best way to conclusively identify controlling secondary mineral phases. Mineralogical analysis by Montana Tech confirmed the presence of a ZnS (Ref. 23).

Attenuation of Cd and Pb due to sulfide precipitation was inconclusive. Speciation modeling showed supersaturation with respect to both CdS and PbS. However, the relatively low solid phase concentrations of these metals in the treatment tanks prevented the identification of any Cd/Pb secondary mineral phases by Montana Tech (Ref. 23). Correlation analysis results for the treatment tank elemental concentrations suggest an alternative attenuation mechanism to sulfide precipitation. If the dominant mechanism for Cd and Pb removal was sulfide precipitation, a correlation between Cd, Pb, and Zn (Appendix F, Figure 23, Table 5) should be observed. A positive correlation was not observed from the September 2004 data set. As such, an alternative mechanism for the removal of Pb and Cd is probable.

5.2.3.2 Phosphate Mineral Precipitation

Speciation modeling identified manganese phosphate as a possible control on Mn concentrations. Further evaluation was required to establish if $MnHPO_4$ was indeed a credible secondary mineral phase. Similarly, formation of strengite (Fe-phosphate) was identified as a possible sink for Fe.

Effluent saturation indices indicate undersaturation with respect to hydroxypyromorphite. Because influent Pb concentrations were very low, adsorption of Pb by hydroxyapatite was unrecognizable. Since the Ca concentrations increased in the effluent relative to the influent, it is highly probable that the organic hydroxyapatite was dissolving not precipitating.

5.2.3.3 Surface Reactions

Adsorption of Pb, Cd, and Mn onto ferrihydrite or the Apatite II^{TM} treatment medium (Ref. 8) would also account for the positive correlation observed between the solid phase concentrations of these metals. Also adsorption onto the whole bone apatite surface was a possibility. Iron oxide staining was observed at the NSM adit and the treatment tank bypass overflow. Large amounts of iron oxide were seen in a photo entitled dewatered apatite with ferric coat, which was taken looking down into one of the reactors. Wright 2004 cites studies that showed Apatite II^{TM} is capable of absorbing up to 5% of its weight in metals. The mineralogical analysis conducted to date was capable of determining that on average 6% of Zn by weight was retained by means of the four listed attenuation mechanisms on the fishbone in the treatment tanks, but it was not capable of characterizing surface reactions such as adsorption. More sophisticated analytical techniques and analysis would be required to make a definitive conclusion regarding the role of this process at the NSM. Figures 5-4, 5-5, and 5-6 are photographs of the apatite medium from this treatment system.

5.3 Effect of Mixing Effluents from the NSM ATS

The configuration of the NSM ATS was such that the effluent waters from the three treatment tanks were mixed before discharge. The variance in the constituents of the effluent waters from each of the treatment tanks induced specific reactions to occur. As the effluents exited the tanks, the water mixed reducing the dissolved contaminants found in the water discharging to Highland Creek. In addition, the bypass water entering the catch basin would be diluted with respect to the concentration of certain constituents, because the bypass water was mixing with the effluent from the ATS.

Geochemical modeling was used to determine the effects of the aforementioned reactions on the quality of the mixed water to determine the quality of water entering Highland Creek and to determine if the catch basin was acting as a hypothetical fourth reactor. The geochemical software PhreeqCI was used in this modeling effort. Six monthly sampling events were selected to be evaluated for this modeling effort. These sampling events were March 19, 2003; May 29, 2003; June 19, 2003; August 19, 2003; February 10, 2004; and May 25, 2004. The events were chosen because a broad range of effluent water compositions as far as oxidizing and reducing conditions and, as such, varying sulfide and Zn concentrations were evident. Additionally, the six samples were representative of the entire project.

The saturation indices results of the geochemical modeling are presented in Table 5-17. According to information in Table 5-17, a ZnS solid species would probably be precipitated from the mixed waters in all of the modeled cases. The specific ZnS specie(s) produced would control the concentration of dissolved Zn in the mixed effluent water. It is also possible that manganese phosphate, elemental sulfur, and FeS would precipitate. Although it is unlikely, due to kinetic considerations, that pyrite would be formed in viable concentrations. The dissolved concentrations of the cationic constituents yielded by the geochemical model for the mixed effluent waters are shown in Table 5-18. The detailed dissolved Zn concentrations in the data were for an amorphous ZnS solid compound. It is entirely probable that the actual concentration of ZnS found in the mixed effluent waters would be substantially lower than the modeled results. Table 5-18 indicates that the modeled concentrations within the mixed effluent water are substantially lower than a simple mixing of the effluents from the three tanks.

5.4 Effect of Mixing Treated Effluent from the ATS and Bypass Water from the NSM

The ATS at the Nevada Stewart consistently treated approximately one-half of the water emanating from the underground mine workings.

The other half of the flow from the mine was allowed to bypass the treatment system. This bypass water was mixed with the treated effluent within the catch basin prior to the entire flow entering Highland Creek.

The chemical composition of these two waters was significantly different in that the treated water was distinctly less aerobic, had low concentrations of dissolved metals, and contained significant quantities of soluble sulfide while the bypass water was more oxidized, contained higher concentrations of dissolved metals, and had very low amounts of soluble sulfide. As was described previously, the variance in the constituents of the bypass water and the mixed effluent water from the treatment tanks induced specific reactions as the waters mixed. These reactions resulted in a reduction in the amount of specific dissolved contaminants found in the mixed water in the catch basin. In addition, the concentration of certain constituents would be reduced in the effluent waters by the effect of dilution.

Geochemical modeling was used to determine the effects of the previous reactions on the quality of the mixed effluent water flowing from the catch basin into Highland Creek. The geochemical software PHREEQCI was used in this modeling effort (Ref. 24). The same six monthly sampling events that were selected for the previous geochemical modeling scenario, which described the mixing of the reactor effluents, were used for this effort.

The saturation indices resulting from the geochemical modeling are presented in Table 5-19. As predicted by the model, a ZnS solid species would very probably be precipitated when the ATS effluent and the NSM bypass waters mixed. The specific ZnS specie(s) produced would control the concentration of dissolved Zn in the mixed effluent water. It is also possible that manganese phosphate, elemental sulfur, and FeS could precipitate. Although, it is unlikely, due to kinetic considerations, that pyrite would be formed in viable concentrations.

The dissolved concentrations of the cationic constituents yielded by the geochemical modeling effort for the mixed effluent waters are shown in Table 5-20. The dissolved concentration of Zn detailed in these data is related to the precipitation of an amorphous ZnS solid compound. It is entirely probable that the actual concentration of ZnS found in the mixed effluent waters would be lower than the modeled results. As can be seen from Table 5-20, the modeled concentrations within the mixed effluent water are significantly lower than a simple mixing of the bypass water and the reactor effluents due to the production of insoluble sulfide-based precipitates.

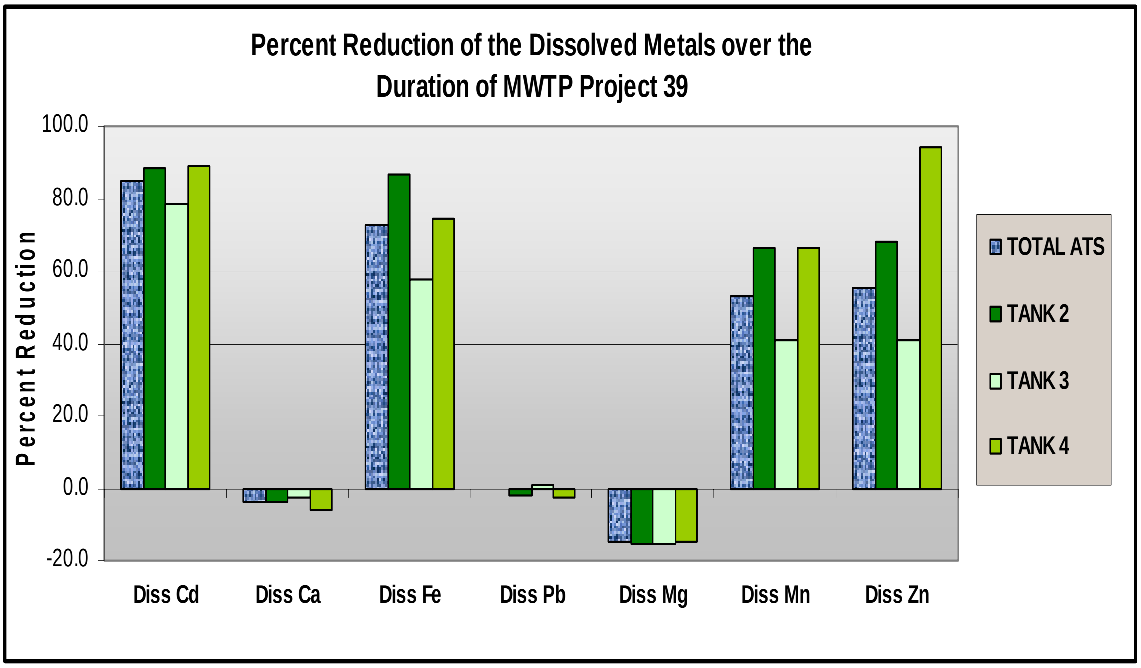


Figure 5-1. Average percent reduction in dissolved metals over the duration of the MWTP, Activity III, Project 39, ATS as compared to the NSM discharge (influent) dissolved metals concentrations.

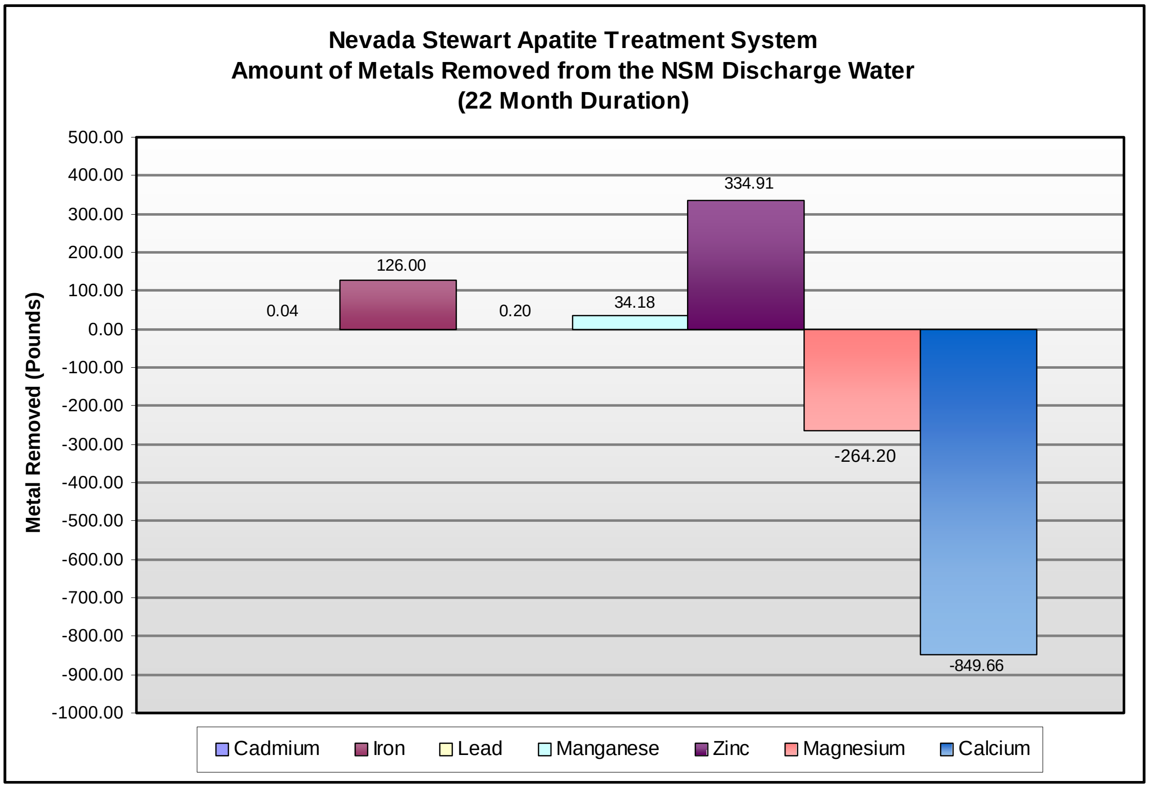


Figure 5-2. Amount of metal removed by the NSM ATS.

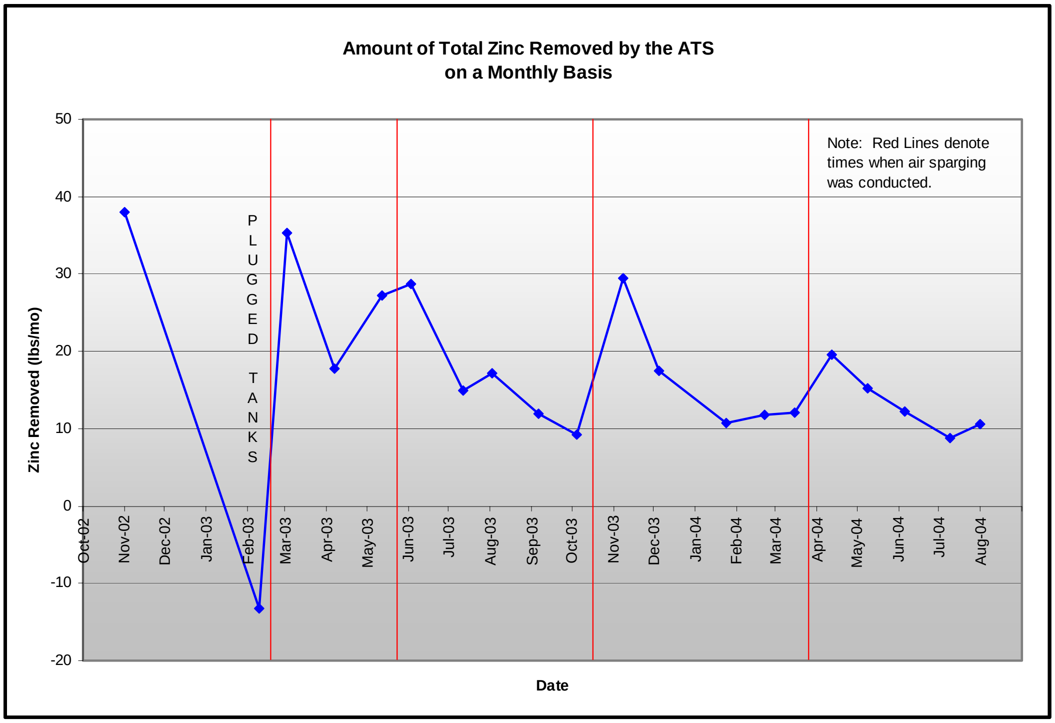


Figure 5-3. Amount of total Zn removed by NSM ATS on monthly basis.

Figure 5-4. Tank 4 (center cell) just prior to the solid phase (total digest) sampling showing the ferrihydrite coated surface.

Figure 5-5. Photo of the fishbone at the end of the project. Bone pieces are from varying depths to compare to the unused bone (Figure 2-16).

Figure 5-6. Tank 4 apatite medium showing the black and white precipitate with minimal ferrihydrite on the surface.

Table 5-1. Zn Percent Reduction for Selected Metals by Sampling Port

Port	Minimum	Median	Mean	Maximum	Standard Deviation
SP2	29.2	58.9	58.4	86.1	15.0
SP3	13.6	34.1	38.6	87.8	20.9
SP4	8.4	93.3	85.9	99.8	20.8
SP4*	72.2	94.1	90.0	99.8	10.3

*Outlier removed for Zn 02/26/2003

Table 5-2. Cd Percent Reduction for Selected Metals by Sampling Port

Port	Minimum	Median	Mean	Maximum	Standard Deviation
SP2	-198.1	89.6	75.1	97.3	66.3
SP2*	82.5	89.9	90.3	97.3	3.7
SP3	-22.1	63.0	57.9	81.6	31.8
SP4	61.4	89.6	88.1	97.3	7.9

*Outlier removed for Cd 08/19/2003

Table 5-3. Pb Percent Reduction for Selected Metals by Sampling Port

Port	Minimum	Median	Mean	Maximum	Standard Deviation
SP2	-214.8	54.2	39.1	94.6	67.0
SP3	-8.4	37.8	35.0	77.5	26.3
SP4	0	52.0	75.5	94.6	29.6

Table 5-4. Fe Percent Reduction for Selected Metals by Sampling Port

Port	Minimum	Median	Mean	Maximum	Standard Deviation
SP2	87.77	96.82	95.60	99.34	3.74
SP3	24.83	54.96	58.87	98.08	26.08
SP4	73.24	92.88	90.47	96.63	6.04

Table 5-5. Mn Percent Reduction for Selected Metals by Sampling Port

Port	Minimum	Median	Mean	Maximum	Standard Deviation
SP2	39.42	73.70	67.82	88.29	16.25
SP3	16.67	43.09	45.43	84.51	22.22
SP4	40.67	63.26	66.90	76.56	9.17

Table 5-6. Ca Percent Reduction for Selected Metals by Sampling Port

Port	Minimum	Median	Mean	Maximum	Standard Deviation
SP2	6.14	3.05	3.27	0	1.64
SP3	4.89	0.21	1.18	2.56	2.11
SP4	9.44	4.99	4.93	1.74	2.75

Table 5-7. Mg Percent Reduction for Selected Metals by Sampling Port

Port	Minimum	Median	Mean	Maximum	Standard Deviation
SP2	1.88	0.12	0.02	1.50	0.98
SP3	1.95	0.23	0.31	2.31	1.05
SP4	2.64	0.23	0.08	2.31	1.18

Table 5-8. Kruskal-Wallis Test and Multiple Comparison Procedure for Zn

Kruskal-Wallis Test: chi-square = 32.4289, df = 2, p-value = 0.0002

Multiple Comparison	Difference*	Statistic	S/NS ($\alpha = 0.05$)
SP2 versus SP3	11.50	7.55	S
SP2 versus SP4	19.60	7.55	S
SP3 versus SP4	31.10	7.55	S

*If the difference > statistic, then statistically significant at the 0.05 level.

Table 5-9. Kruskal-Wallis Test and Multiple Comparison Procedure for Cd

Kruskal-Wallis Test: chi-square = 17.0977, df = 2, p-value = 0.0002

Multiple Comparison	Difference*	Statistic	S/NS ($\alpha = 0.05$)
SP2 versus SP3	19.66	9.16	S
SP2 versus SP4	0.79	9.16	NS
SP3 versus SP4	18.87	9.16	S

*If the difference > statistic, then statistically significant at the 0.05 level.

Table 5-10. Kruskal-Wallis Test and Multiple Comparison Procedure for Pb

Kruskal-Wallis Test: chi-square = 4.3512, df = 2, p-value = 0.1135

Multiple Comparison	Difference*	Statistic	S/NS ($\alpha = 0.05$)
SP2 versus SP3	9.53	10.55	NS
SP2 versus SP4	0.37	10.55	NS
SP3 versus SP4	9.89	10.55	NS

*If the difference > statistic, then statistically significant at the 0.05 level.

Table 5-11. Kruskal-Wallis Test and Multiple Comparison Procedure for Ca

Kruskal-Wallis Test: chi-square = 18.5928, df = 2, p-value = 0.0001			
Multiple Comparison	**Difference***	**Statistic**	**S/NS (= 0.05)**
SP2 versus SP3	13.00	8.98	S
SP2 versus SP4	10.16	8.98	S
SP3 versus SP4	23.16	8.98	S

*If the difference > statistic, then statistically significant at the 0.05 level.

Table 5-12. Kruskal-Wallis Test and Multiple Comparison Procedure for Mg

Kruskal-Wallis Test: chi-square = 1.2035, df = 2, p-value = 0.5479			
Multiple Comparison	**Difference***	**Statistic**	**S/NS (= 0.05)**
SP2 versus SP3	5.71	10.87	NS
SP2 versus SP4	1.55	10.87	NS
SP3 versus SP4	4.16	10.87	NS

*If the difference > statistic, then statistically significant at the 0.05 level.

Table 5-13. Kruskal-Wallis Test and Multiple Comparison Procedure for Fe

Kruskal-Wallis Test: chi-square = 29.33, df = 2, p-value = 0			
Multiple Comparison	**Difference***	**Statistic**	**S/NS (= 0.05)**
SP2 versus SP3	29.05	7.59	S
SP2 versus SP4	12.32	7.59	S
SP3 versus SP4	16.74	7.59	S

*If the difference > statistic, then statistically significant at the 0.05 level.

Table 5-14. Kruskal-Wallis Test and Multiple Comparison Procedure for Mn

Kruskal-Wallis Test: chi-square = 12.6285, df = 2, p-value = 0.0018			
Multiple Comparison	**Difference***	**Statistic**	**S/NS (= 0.05)**
SP2 versus SP3	29.05	9.68	S
SP2 versus SP4	12.32	9.68	S
SP3 versus SP4	16.74	9.68	S

*If the difference > statistic, then statistically significant at the 0.05 level.

Table 5-15. Average Percent Metals Reduction Achieved for the Duration of the MWTP, Activity III, Project 39, NSM ATS for Full ATS and Each Treatment Tank

Average Percent Reduction for the Duration of the Project – Apatite Treat System				
Parameter	**Total ATS**	**Tank 2**	**Tank 3**	**Tank 4**
Dissolved Cd	84.9	88.3	78.8	88.7
Dissolved Ca	-3.5	-3.9	-2.6	-6.2
Dissolved Fe	72.9	86.7	57.8	74.4
Dissolved Pb	-0.3	-2.2	0.9	-2.4
Dissolved Mg	-14.9	-15.2	-15.3	-14.7
Dissolved Mn	52.8	66.6	40.7	66.3
Dissolved Zn	55.4	68.0	40.8	94.5
Sulfate (mg/L)	0.8	0.2	2.1	3.4

Table 5-16. Comparison of Regulatory Discharge Limits with the NSM ATS Effluent and Influent Values for the First and Last Sampling Events of the Project

Dissolved Metals (mg/L)	Zn	Cd	Pb	Fe	Mn	Sulfate
Drinking Water Standards[1]	5.0[*]	0.01	0.05	0.30[*]	0.05[*]	250[*]
Influent (SP1) 11/02	5.64	0.0005	0.0013	0.731	0.691	257
Influent (SP1) 8/04	8.00	0.0005	0.0012	0.496	0.608	349
Tank 2 11/02	0.039	0.00005	0.0013	0.142	0.349	254
Tank 2 8/04	3.70	0.00003	0.0012	0.031	0.071	351
Tank 3 11/02	0.0243	0.00007	0.0013	0.077	0.235	191
Tank 3 8/04	4.400	0.00003	0.0012	0.108	0.182	349
Tank 4 11/02	0.686	0.00005	0.0013	0.142	0.384	259
Tank 4 8/04	0.0096	0.00003	0.0012	0.160	0.155	315

All values on the table are as mg/L.

[*] National Secondary Drinking Water Regulations.

[1] Federal maximum contaminant level for protection of drinking water.

Table 5-17. Saturation Indices for Mixed Effluent

Sample Date	$MnHPO_4$	Pyrite	Sphalerite	Wurtzite	ZnS (am)	Hydroxyapatite	Sulfur	Mackinawite
3/19/03	2.46	22.56	3.06	1.04	0.37	4.00	10.05	0.40
5/29/03	1.92	20.07	4.63	2.61	1.95	- 0.19	8.63	- 0.68
6/19/03	2.11	22.64	3.46	1.44	0.78	2.53	10.13	0.39
8/19/03	1.89	18.01	6.02	4.00	3.33	1.50	7.83	- 1.93
2/10/04	1.85	19.23	5.73	3.79	3.16	1.31	9.74	- 2.23
5/25/04	0.85	15.82	5.03	3.02	2.35	- 3.73	7.59	- 3.89
8/17/04	0.73	19.94	5.94	3.91	3.27	0.38	9.97	-2.01

Table 5-18. Dissolved Concentrations of Cationic Constituents for Mixed Effluent

Sample Date	Ca mg/L	Fe mg/L	Mg mg/L	Mn mg/L	Zn mg/L
3/19/03	93.80	0.05	40.21	0.02	0.52
5/29/03	92.71	0.30	41.70	0.01	0.17
6/19/03	97.53	0.18	41.67	0.01	0.18
8/19/03	92.83	0.17	41.2	0.01	0.02
2/10/04	94.99	0.19	39.08	0.01	1.62
5/25/04	93.84	0.07	41.47	0.04	4.77
8/17/04	105.00	0.07	45.00	0.01	0.96

Table 5-19. Saturation Indices for a Mixture of Bypass Water and the Reactor Effluents

Sample Date	$MnHPO_4$	Pyrite	Sphalerite	Wurtzite	ZnS (am)	Hydroxyapatite	Sulfur	Mackinawite
3/19/03	1.98	20.33	4.06	2.39	0.87	1.41	9.64	- 0.59
5/29/03	1.74	19.09	6.24	4.06	3.27	- 2.08	7.91	- 1.28
6/19/03	1.83	19.13	5.63	3.49	2.42	1.32	8.63	- 1.86
8/19/03	1.28	18.35	5.71	3.54	2.61	- 1.81	8.27	- 2.07
2/10/04	1.13	16.49	4.39	2.77	1.08	- 2.27	7.19	- 2.94
5/25/04	0.79	12.71	3.16	1.52	0.21	- 6.36	6.14	- 4.71
8/17/04	1.61	17.86	5.03	3.47	1.89	-3.77	7.84	- 3.64

Table 5-20. Dissolved Concentrations of Cationic Constituents for a Mixture of Bypass Water and the Reactor Effluents

Sample Date	Ca mg/L	Fe mg/L	Mg mg/L	Mn mg/L	Zn mg/L
3/19/03	91.40	0.27	40.36	0.01	0.23
5/29/03	90.75	0.46	41.40	0.01	0.09
6/19/03	96.61	0.43	41.63	0.01	0.78
8/19/03	91.77	0.35	26.05	0.02	0.84
2/10/04	93.35	0.47	39.04	0.03	1.96
5/25/04	89.62	0.17	39.83	0.05	5.14
8/17/04	104.00	0.28	45.17	0.02	0.89

6. ATS Cost Analysis

A cost analysis was performed for the ATS demonstration installation and long-term monitoring/evaluation performed by DOE and the EPA MWTP, respectively. Required elements for the ATS included the scope of work, system design, pre-installation materials testing, ATS installation, simple analytical analysis, monthly monitoring, reporting, ATS maintenance (quarterly permeability enhancement), and project closure. The additional research used to determine the effectiveness of the ATS involved geochemical modeling, extensive analytical analysis, SEM/EDX, XRD, physical analysis, monthly sampling, extensive reporting, statistics, toxicology testing, and increased project management all under the guidance of the project QAPP.

For this analysis, a hypothetical real-world cost for implementation of an ATS system in a field setting is presented.

Included in Table 6-1 are estimations of the total unit cost for an ATS project without the research aspects attached to this specific projects. The assumptions are that these costs include installation of a system for remediation of a site that would not require the extensive oversight, research, analytical, modeling, and reporting needs of the demonstration project presented in this report. Discount rates are based on Office of Management and Budgets projected discount rates for Cost-Effectiveness, Lease –Purchase, Internal Government Investment, and Asset Sale Analyses that are published yearly. The results of the cost analysis indicate that the net present value of the unit cost to treat a thousand gallons of water ranges from $6.30 over 2 years to $1.20 over 30 years.

Table 6-1. Estimations of the Percent Total Unit Cost for an ATS Project Without Research Aspects Attached

Items for Hypothetical Barrier Costs	Cost
Installation Costs,	
Manager, 6 months	$1,800
QAPP	$5,000
Testing	$3,100
Design and Specifications	$6,500
Documentation	$1,400
Install Monitoring Wells	$1,500
Construct Barrier	$67,700
Total Installation Costs	$87,000
Operating and Maintenance (O&M) Costs	
Repairs	$10,300
Sampling and Surging	$14,500
Analysis	$3,800
Total O&M costs for 22 months	$28,600
Equivalent yearly O&M costs	$15,600
2 years	
Installation	$87,000
Net present value (NPV) of cost for O&M, $15,600 per year for 2 years at 3.7%	$29,600
NPV of cost	$116,600
Unit cost per 1,000 gallons treated	$6.30
10 years	
Installation	$87,000
NPV of cost for O&M, $15,600 per year for 10 years at 4.6%	$122,800
NPV of cost	$209,800
Unit cost per 1,000 gallons treated	$2.30
20 years	
Installation	$87,000
NPV of cost for O&M, $15,600 per year for 20 years at 4.9%	$196,000
NPV of cost	$283,000
Unit cost per 1,000 gallons treated	$1.50
30 years	
Installation	$87,000
NPV of cost for O&M, $15,600 per year for 30 years at 5.2%	$234,400
NPV of cost	$321,400
Unit cost per 1,000 gallons treated	$1.20

7. Summary of Quality Assurance Activities

7.1 Background

The following is a summary of the quality assurance (QA) activities associated with MWTP Activity III, Project 39, *Permeable Treatment Wall Effectiveness Monitoring, Nevada Stewart Mine Site*. Analytical samples and field data were collected according to the schedule outlined in the approved project-specific QAPP document. All field and laboratory data available has been evaluated to determine the usability of the data. Critical analyses were flume/weir water depth and dissolved metals [Al, Sb, As, Be, Cd, Ca, Cr, Cu, Fe, Pb, Mg, Mn, Ni, K, P, Na, Se, Ag, Si, titanium (Ti), and Zn]. In February 2004, an addendum to the QAPP was written to reflect a reduction in the amount of dissolved metals that were analyzed for As, Al, Ca, Cu, Cd, Fe, Pb, Mg, Mn, K, Na, Si, and Zn. A critical analysis is an analysis that must be performed to determine if project objectives were achieved. Data from noncritical analyses were also evaluated.

7.2 Project Reviews

An external technical systems audit of the project field activities was performed by David Gratson of Neptune and Company (subcontractor to EPA) on September 23, 2003. There were no findings, three observations, and one additional technical comment identified during the audit.

The observations included using expired pH calibration buffer solutions, using an ORP different than the meter specified in the QAPP, and other general comments on minor revisions to the QAPP. Efforts were made to ensure that pH calibration buffer solutions used after the audit were fresh solutions and the expiration data was documented in the field logbook during each sampling event. An addendum to the QAPP was developed to correct the other two observations. The additional technical comment pertained to communications between the MSE and EPA project managers. Significant operational modifications were documented and communicated to the EPA project manager.

7.3 Data Evaluation

Data that was generated throughout the project was validated. The purpose of data validation is to determine the usability of data that was generated during a project. Data validation consisted of two separate evaluations: an analytical evaluation and a program evaluation.

7.3.1 Analytical Evaluation

An analytical evaluation of all data was performed to determine the usability of the data that was generated by HKM Laboratory for the project. Laboratory data validation was performed using *USEPA Contract Laboratory Program (CLP) National Functional Guidelines for Inorganics Data Review* (USEPA 1994) as a guide. The data quality indicator objectives for critical measurements were outlined in the QAPP and were compatible with project objectives and the methods of determination being used. The data quality indicator objectives were method detection limits (MDLs), accuracy, precision, and completeness. Control limits for each of these objectives are summarized in Tables 7-1 and 7-2. The quality control (QC) criteria were also used to identify outlier data and to determine the usability of the data for each analysis.

Measurements that fell outside of the control limits specified in the QAPP, or for other reasons were judged to be outlier, were flagged appropriately to indicate that the data was judged to be estimated or unusable. All data requiring flags are summarized in Table 7-3.

At the beginning of the project, HKM Laboratory used influent samples for QC. The CLP spiking levels were appropriate for all analytes except Zn. The concentration of Zn in the influent samples ranged from six to ten times higher than the spiking level. Because the sample concentration for Zn was greater than four times the spike concentration, HKM Laboratory was not required to meet a recovery limit; however, MSE calculated spike recoveries. With only two exceptions

(February 2002 and May 2002), the spike recoveries for Zn were within the acceptable range of 75% to 125%. Serial dilutions were also within acceptable limits. This indicated that there were no matrix effects for Zn in these samples. December 2003 samples were first set where HKM Laboratory began using the effluent samples for QC, thereby, rectifying the issue of the sample concentration for Zn being greater than four times the spike concentration. All spike recoveries for Zn from December 2003 through August 2004 samples were within the acceptable range.

7.3.2 Program Evaluation

Program evaluations include an examination of data generated during the project to determine that all field QC checks were performed and within acceptable tolerances. Program data that was inconsistent or incomplete and did not meet the QC objectives outlined in the QAPP were viewed as program outliers and were flagged appropriately to indicate the usability of the data.

7.3.2.1 Flume/Weir Water Depth

A 60-degree trapezoidal flume was used to measure total groundwater flow from the adit. This flume was located upstream of the retention basin and the bypass pipe.

Weir water levels and flows were measured with a Thel-Mar volumetric weir. Thel-Mar weirs were installed in 10-inch pipes to measure the outflow from each of the three apatite treatment tanks and also in a single 6-inch pipe to measure flow into the ATS.

Untreated flow was calculated by simple subtraction: total flow measured in the flume minus flow measured in the weir leading to the ATS equals flow that bypassed the treatment system.

The surface water flow rate measurements were obtained in accordance with the procedures outlined in the QAPP. No surface water flow rate data were judged to be outlier.

7.3.2.2 Dissolved Metals

Dissolved metals analysis was a critical analysis for this project. Aqueous samples were collected from the four sampling locations during each sampling event, as well as a field duplicate sample from a predetermined sampling location and a field blank. Sampling procedures for the collection of the aqueous samples outlined in the QAPP were followed. The samples were taken to HKM Laboratory for analysis by ICP Emission Spectrometer (ICP-ES). No dissolved metals data were judged to be outlier.

7.4 Quality Assurance Summary

In general, sampling personnel conducted QA/QC activities for this project in accordance with the procedures outlined in the QAPP. All field duplicates and field blanks were collected, field instrumentation properly calibrated, and critical activities documented in the field logbook. The sample NSM SP1 052504 collected May 25, 2004 was flagged unusable because the repeatability of the field duplicate was outside the acceptable range of ≤ 20% relative percent difference (RPD) for total and dissolved metals. During this sampling event, other personnel not previously used on this project collected the samples. If at all possible, the same personnel should be used for sampling activities; otherwise, other personnel need to receive proper training.

Table 7-1. QA objectives for Accuracy, Precision, MDL, and Completeness

Measurement	Units	MDL	Precision[1]	Accuracy	Completeness[2]
Flume/Weir water depth	Inches	0.03	N/A	±5%[3]	95%
Dissolved Metals	mg/L	See Table 7-2	≤20% RPD	75%-125% spike recovery	95%

[1] Precision will be determined by the RPD of duplicates, unless otherwise indicated.

[2] Completeness is based on the number of valid measurements, compared to the total number of samples.

[3] Accuracy of weirs/flumes will be ensured by installing flumes and weirs according to SOP H6-6 and by avoiding installation locations that could adversely affect weir/flume accuracy (i.e., approach conditions do not allow uniform velocity distribution, damage to weirs or flumes, changes in weir or flume dimensions). In addition, manual flow rate measurements will give an indication of whether the weirs and flumes are returning reasonable flow rate measurements.

Table 7-2. IDLs for ICP Analysis of Dissolved Metals

Analyte	IDL (μg/L)	ICP CRDL (μg/L)
Al	24.0	200
Sb	29.5	60
As	29.5	59.1
Be	2.4	5
Cd	4.52	5
Ca	14.1	5000
Cr	10.0	10
Cu	2.4	25
Fe	10.0	100
K	21.2	5000
P	36.8	184.2
Mg	40.0	5000
Mn	2.6	15.0
Ni	10.9	40
Se	57.2	114.3
Ag	3.7	10
Na	16.3	5000
Ti	3.2	15.8
Zn	5.9	20
Pb	24.0	48.0

Table 7-3. Summary of Flagged Data for Activity III, Project 39

Date of Collection	Sample ID	Analysis	Quality Criteria	Flag	Comment
6/19/03	NSM SP4 061903	Total Zn	≤ 20% RPD	J	RPD > 20%; the associated samples should be flagged J for total Zn
7/280/03	NSM SP2 072803 NSM SP3 072803 NSM SP4 072803	Total Fe	Blank concentration > CRDL	UJ	The field blank sample showed significant contamination; the associated samples should be flagged UJ for total Fe
11/25/03	NSM SP4 112503	Dissolved Zn	≤ 20% RPD	J	RPD > 20%; the associated samples should be flagged J for dissolved Zn
5/25/04	NSM SP1 052504	Dissolved and Total Metals	≤ 20% RPD	R	RPD > 20% for all dissolved and total metals; the associated samples should be flagged R for dissolved and total metals
8/17/04	NSM SP1 081704	NH_4	≤ 20% RPD	J	RPD > 20%; the associated sample should be flagged J for NH_4
8/17/04	NSM SP4 081704	Dissolved Se	75% – 125% recovery of spike	J	Spike recovery < 75%; the associated sample should be flagged J for dissolved Se
8/17/04	NSM SP1 081704 NSM SP2 081704 NSM SP3 081704 NSM SP4 081704	Total Si Dissolved Si	Blank concentration > CRDL	UJ	The field blank sample showed significant contamination; the associated samples should be flagged UJ for total and dissolved Si

Data Qualifier Definition:
J – The measurements are estimated.
UJ – The measurements are estimated and may be inaccurate or imprecise.

8. Conclusions and Recommendations

The MWTP, Activity III, Project 39, *Permeable Treatment Wall Effectiveness Monitoring, Nevada Stewart Mine Site* was conducted to determine the effectiveness of an ATS and to identify the attenuation mechanisms functioning to reduce the dissolved metals in the adit mine discharge. Overall, the system was effective at reducing the metals loading in the treated NSM adit discharge. Main conclusions drawn from MSE's, EPA's, Golder's, and Montana Tech's contributions regarding this demonstration project are as follows.

- The system effectively attenuates Zn, Cd, Pb, Fe, and Mn, as evidenced by decreases in the aqueous phase concentrations between the influent and effluent, and the increases in the solid phase concentrations of these constituents within the treatment tanks.
- The possible attenuation mechanisms reducing the metals loading in the treated NSM water include:
  - Phosphate mineral precipitation, where Apatite II™ continuously supplies phosphate to solution to exceed the solubility limits of various metal-phosphate phases. It is possible that Mn was removed by this process and because this is a slower process, the characteristics of Tank 4 provided optimal conditions for this process to occur, even though the process could have occurred in Tanks 2 and 3.
  - Biological reduction, resulting in sulfide precipitation, where Apatite II™ supplies both P and readily-bioavailable organics (collagen) at concentrations that stimulate microbial activity within the treatment tanks, occurred in all of the tanks. However, Tank 4, which had the lowest flow rate, recorded the highest hydrogen sulfide gas concentrations, SRB counts, and sulfide concentrations reflective of a strong biological reductive environment. The other tanks also, exhibited the same characteristics but not to the same degree.
  - Nonspecific metal adsorption (surface chemi-adsorption), where Apatite II™ adsorbs metals was another potential metals attenuation mechanism. A quantitative amount of metals adsorbed by the apatite is unknown because the laboratory instrumentation was not capable of determining this.
  - Buffering, where neutral pH is effective at precipitating many metal phases, the NSM near-neutral water at the NSM was minimal. However, increasing pH and alkalinity, especially during the spring of 2003, possibly affected Fe oxidation and, therefore, precipitation and subsequent adsorption of other metals.
- All direct analytical evidence pointed to the precipitation of ZnS as the dominant mechanism for Zn attenuation within the treatment tanks. The lowest effluent Zn concentrations occurred in association with elevated sulfide concentrations, primarily in Treatment Tank 4, which had the lowest ORP and DO. Additionally, mineralogical analysis and evaluation by Montana Tech confirmed the presence of ZnS on the surface of the fishbone apatite.
- No direct analytical evidence could be developed to ascertain the manner in which the treatment process removed Cd and Pb from the influent water. However, speciation modeling by Golder showed supersaturation with respect to CdS and PbS (Appendix D). Correlation analysis results, also by Golder, for the treatment tank elemental concentration suggested but could not verify alternative mechanisms for Pb and Cd removal (i.e., phosphate mineral precipitation and/or surface adsorption).

- Speciation modeling identified manganese phosphate as a possible control on Mn concentrations, especially in Tank 4 as its effluent had high concentrations of total phosphate, but this was not directly verified.
- Depending on the redox conditions within each treatment tank, precipitation of ferrihydrite**,** or iron phosphate (strengite), potentially controlled the Fe concentrations. Substantial quantities of ferrihydrite were visible in the center cell of Tank 3 (Figure 5-4).
- Treatment tanks having lower flows and longer retention times removed metals to a greater degree. Tank 4, having the lowest flow rate, had approximately 95% Zn removal efficiency.
- The mineralogical analysis conducted was not capable of characterizing the surface reactions such as adsorption. However, the solid phase analysis indicated that between 6% and 36% Zn was precipitated onto the surface of the Apatite II™ on a microscopic basis. The sulfide adhered to the surface of the bone probably due to the presence of sulfide producing colonies of bacteria. Smooth surfaces exhibited less metal than rough surfaces.
- The increase in dissolved Ca concentrations in the effluent was caused by the dissolution of the Ca from the fishbone in the treatment tanks.
- A detrimental effect of Fe deposition on the surface of the bone pieces is that it armors the surface that decreases the number of sites available for adsorption of the other target ions and the surface area that is available for dissolution.

__Recommendations__ for further field installation include the following.

- Residence time needs to be increased either by increasing the volume (length of flow path) of the treatment system, decreasing the flow rate, or both.
- Higher concentrations of Fe should be eliminated by some other means, with apatite used as a polishing step within a treatment system to avoid adsorption capacity being diminished in the presence of iron and to avoid likely plugging problems.
- Future apatite treatment systems need to enhance the permeability of the system to maximize the efficiency of the treatment medium for metals removal. Periodic air sparging of the media proved to be an effective way to enhance permeability of the media and reestablish flow when the system was plugged. Future system designs need to improve the hydraulics of the tank systems, thus, preventing clogging and the formation of preferential flow paths through the treatment system. Furthermore, the systems need to be designed to process fluctuating flows resulting from seasonal flow impacts. Also, to ensure that tanks remain level throughout operation, a stable base is necessary to avoid settling of the tanks and associated disruptions in flow.
- The media at the treatment tank entrance becomes loaded first because of precipitation of metals, biological metal reduction, and adsorption of metal on the surface of the apatite medium. As a result, there is a gradual loss of effectiveness of the treatment provided by the media. This process will need to be addressed in the design of future systems.

9. References

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Appendix A

Nevada Stewart Mine Monthly Field Data Results

Appendix B

EPA Toxicity Testing Reports

Appendix C

Montana Tech's Final Report
on the Evaluation of Apatite II™ Media
from the Nevada Stewart Mine Apatite Treatment System

Appendix D

Golder Associates Geochemical Report

Appendix E

Solid Phase Digestion Results

Appendix F

EPA Statistical Analysis

EPA/600/R-06/153
February 2007

Mine Waste Technology Program

Permeable Treatment Wall Effectiveness Monitoring Project Nevada Stewart Mine

Appendices A through F

Appendix A

Nevada Stewart Mine Monthly Field Data Results

App A - Nev Stew Graphs Complete Aug 03, xls

App A - Monthly Field Data (worksheet)

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results										
FLOW ANALYSIS AT NS ADIT	approx.	installed flume								
60 DEG. TRAP. FLUME READING (FT)	not installed	0.36	0.37	0.4						
FLUME FLOW (gpm)	50	47	50.5	62						
Sampling Month	**Baseline Sampling Events before the System was Constructed.**			**November 2002 - Baseline Sampling Results**						
					(Duplicate)					
Sample Location	NS Adit	NS Adit	NS Adit	Sample Port 1	Sample Port 1	Sample Port 2	Sample Port 3	Sample Port 4	Upstream	Downstream
Sample Date:	7/18/2002	7/23/2002	9/23/2002	11/18/2002	11/18/2002	11/18/2002	11/18/2002	11/18/2002	11/18/2002	11/18/2002
Sample #:	NS71802	NS72302	NS03-9/23/02	SP1NSM11/18/02	SP5NSM11/18/02	SP2NSM11/18/02	SP3NSM11/18/02	SP4NSM11/18/02	SPUSNSM111802	SPDSNSM111802
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:	Baseline*	Baseline*	Baseline*	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
INFLUENT FLOW AT TANK #1 - 6 IN. TEE (gpm)		nc	nc	19.78	19.78					
FLOW (gpm) AT 10 IN. TEE at Sample Port 2		nc	nc	8.67	8.67					
FLOW (gpm) AT 10 IN. TEE at Sample Port 3		nc	nc	1.35	1.35					
FLOW (gpm) AT 10 IN. TEE at Sample Port 4		nc	nc	8.62	8.62					
TOTAL EFFLUENT FLOW FROM TANKS #2, #3, #4 (gpm)				18.64	18.64					
Field Analysis										
pH:	6.8	7.01	6.78	6.76	6.84	6.67	6.69	6.81	6.29	6.42
Temperature (°C):	9.8	11.8	9.9	9.9	9.9	9.7	9.4	9.7	4.8	4.8
Conductivity (µS/cm):	764	743.00	807.00	790.00	794.00	855	1043	821	59	66
Orp/Eh (mv):	270	bad probe	67.60	-32.00	-31.00	-271	-242	-285	-80	-90
Dissolved Oxygen (mg/l):	2.42	bad probe	1.87	6.81	6.80	0.73	1.56	0.71	11.09	10.82
DO (%)										
Laboratory Analysis:										
Dissolved Metals (ug/l)										
Al	46.9	46.9	24	25.4	25.4	25.4	25.4	25.4		
Sb	2.2	2.4	43.2	26.7	26.7	26.7	26.7	26.7		
As	2	3.4	1.6	1.2	1.2	1.2	1.2	1.2		
Be	1.2	1.2	2.4	1.1	1.1	1.1	1.30	1.1		
Cd	0.27	0.38	0.33	0.29	0.34	0.05	0.07	0.05	1.50	1.80
Ca	91700	89700	92900	93600	92200	98800	99600	99500		
Cr	10	10	10	9.00	9.00	9.00	9.00	9.00		
Cu	1.5	1.5	2.4	1.4	2.10	1.4	3.00	1.90		
Fe	1030	655	995	731	758	142	77	142		
Pb	1.57	1.5	0.63	1.30	1.50	1.30	1.30	1.30	3.10	3.70
Mg	41800	41200	42100	42700	41000	42400	41700	41800		
Mn	660	561	593	619	619	349	235	384		
Hg	0.08	0.08	0.18	0.1	0.10	0.10	0.10	0.10		
Ni	20.6	20.6	10.9	14.2	14.2	14.2	14.2	14.2		
K	546	571	533	583	552	990	1630	640		
Se	1.4	1.7	2.2	1.60	1.60	1.60	1.60	1.60		
Si	8440	8230	7660	7840	7630	7870	8490	7880		
Ag	3.7	3.7	3.7	4.4	4.4	4.4	4.4	4.4		
Na	7210	7120	7200	7930	7470	8600	9780	7930		
Ti	0.62	1.6	2.8	1.4	1.40	1.40	1.40	1.40		
Zn	4310	4110	5290	5640	5610.0	39.4	24.3	68.6	597.0	916.0

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results										
FLOW ANALYSIS AT NS ADIT	approx.	installed flume								
60 DEG. TRAP. FLUME READING (FT)	not installed	0.36	0.37	0.4						
FLUME FLOW (gpm)	50	47	50.5	62						
Sampling Month	Baseline Sampling Events before the System was Constructed.			November 2002 - Baseline Sampling Results						
					(Duplicate)					
Sample Location	NS Adit	NS Adit	NS Adit	Sample Port 1	Sample Port 1	Sample Port 2	Sample Port 3	Sample Port 4	Upstream	Downstream
Sample Date:	7/18/2002	7/23/2002	9/23/2002	11/18/2002	11/18/2002	11/18/2002	11/18/2002	11/18/2002	11/18/2002	11/18/2002
Sample #:	NS71802	NS72302	NS03-9/23/02	SP1NSM11/18/02	SP5NSM11/18/02	SP2NSM11/18/02	SP3NSM11/18/02	SP4NSM11/18/02	SPUSNSM111802	SPDSNSM111802
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:	Baseline*	Baseline*	Baseline*	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
Total Metals (ug/L)										
Al	46.9	46.9	24.00	25.4	25.4	25.4	25.4	25.4		
Sb	2.9	9.6	28.80	26.7	26.7	26.7	26.7	26.7		
As	0.96	3.4	1.80	1.2	1.2	1.2	2.30	1.2		
Be	1.2	1.2	2.40	1.1	1.1	1.1	1.1	1.1		
Cd	0.27	0.37	0.20	0.29	0.28	0.05	0.05	0.11	1.60	2.30
Ca	88500	91200	101000.00	98300	94800.00	100000	99600	99600		
Cr	10	10	10.00	9.00	9.00	9.00	9.00	9.00		
Cu	1.5	1.5	2.40	1.4	2.30	1.80	2.70	1.83		
Fe	1510	1150	1540.00	1410	1370	170	151	148		
Pb	3.2	5.2	0.63	2.1	2.40	1.40	1.40	1.70	4.60	6.80
Mg	40400	42100	45000.00	43400	43400	43400	43400	43400		
Mn	639	573	659.00	655	636	355	247	383		
Hg	0.08	0.08	0	0	0.10	0.11	0.11	0.11		
Ni	20.6	20.6	10.90	14.2	14.2	14.2	14.2	14.2		
K	546	601	588.00	578	544.00	676.00	1000.00	604.00		
Se	3.4	1.4	2.10	1.6	1.6	1.6	1.6	1.6		
Si	8193	8320	8200.00	8180	7860	7880	8390	7770		
Ag	3.7	3.7	3.70	4.4	4.4	4.4	4.4	4.4		
Na	6960	7620	7680.00	7970	7690	8310	8800	7990		
Ti	0.62	1.6	1.50	1.4	1.4	1.4	1.4	1.4		
Zn	4190	4230	5850	6030	5810	825	724	860	583	929
Acidity (mg/l)	< 10	< 10	10	<10		<10	<10	<10		
Alkalinity (mg/l)	120	116	118	118		146	288	135		
Ammonia (mg/l)	0.05	<0.05	118	0.11		6.8	32.9	3		
Chloride (mg/l)	< 5	< 5	<5	<5		<5	<5	<5		
Fluoride (mg/l)	< 0.5	< 0.5	<0.5	<0.5		<0.5	<0.5	<0.5		
Nitrate/Nitrite-N	0.09	<0.05	<0.05	0.11		0.08	0.16	2.9		
Nitorgen Kjeldahl (mg/l)	0.3	0.16	0.09	0.06		8	38	3.4		
Dis Orthophosphate (mg/l)	<0.05	<0.05	<0.05	<0.5		0.62	0.82	2.2	0.05	0.05
Total Phosphorus (mg/l)	0.44	<0.05	0.8	0.37		1.42	8.36	2.98	0.34	0.95
Total Dissolved Phosphorus (mg/l)	0.1	<0.05	0.65	0.2		1.31	7.83	1.34	0.21	0.77
Sulfate (mg/l)	270	268	155	257		254	191	259		
Sulfide (mg/l)	0.77	0.57	2.3	<0.5		5.5	62	3.5		
Total Coliform Bacteria, cnt/100ml			<1							
Fecal Coliform, Absent/Present			<1 , absent	<1 , absent				<1 , absent		
** Coliform sample location at Port 1 not a Flume.										

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results						
FLOW ANALYSIS AT NS ADIT						
60 DEG. TRAP. FLUME READING (FT)						
FLUME FLOW (gpm)	43.64					
Sampling Month	NOTE: February 26, 2003 - Limited Target Sampling Results - Partially Plugged at Catch Basin					
		(Duplicate)				
Sample Location	Sample Port 1	Sample Port 1	Sample Port 2	Sample Port 3	Sample Port 4	Bottom of Ret.Basin
Sample Date:	37678.00	37678.00	37678.00	37678.00	37678.00	37678.00
Sample #:	SP1NSM2/26/03	SP5NSM2/26/03	SP2NSM2/26/03	SP3NSM2/26/03	SP4NSM2/26/03	NSM-Tank 1 bottom
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water
Sample Type:	Baseline	Baseline	Select Target	Select Target	Select Target	Select Target
INFLUENT FLOW AT TANK #1 - 6 IN. TEE (gpm)	5.85					
FLOW (gpm) AT 10 IN. TEE at Sample Port 2			Flows not Taken	Due to Plugged	Catch Basin	
FLOW (gpm) AT 10 IN. TEE at Sample Port 3						
FLOW (gpm) AT 10 IN. TEE at Sample Port 4						
TOTAL EFFLUENT FLOW FROM TANKS #2, #3, #4 (gpm)						
Field Analysis						
pH:	6.96	6.96	7.11	7.03	7.98	
Temperature (°C):	9.79	9.76	7.11	7.97	7.98	
Conductivity (µS/cm):	782.00	782.00	1698.00	2073.00	1094.00	
Orp/Eh (mv):	16.90	16.90	-139.60	-127.10	-107.20	
Dissolved Oxygen (mg/l):	6.18	6.18	0.60	0.76	0.80	
DO (%)						
Laboratory Analysis:						
Dissolved Metals (ug/l)						
Al						
Sb						
As						
Be						
Cd						
Ca	90000.00		95100.00	95200.00	93900.00	
Cr						
Cu						
Fe	414.00		167.00	81.70	334.00	
Pb						
Mg	40300.00		40800.00	41300.00	41200.00	
Mn	618.00		271.00	356.00	607.00	
Hg						
Ni						
K						
Se						
Si						
Ag						
Na						
Ti						
Zn	6340.00		30.50	1120.00	5470.00	

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results						
FLOW ANALYSIS AT NS ADIT						
60 DEG. TRAP. FLUME READING (FT)						
FLUME FLOW (gpm)	43.64					
Sampling Month	NOTE: February 26, 2003 - Limited Target Sampling Results - Partially Plugged at Catch Basin					
		(Duplicate)				
Sample Location	Sample Port 1	Sample Port 1	Sample Port 2	Sample Port 3	Sample Port 4	Bottom of Ret.Basin
Sample Date:	37678.00	37678.00	37678.00	37678.00	37678.00	37678.00
Sample #:	SP1NSM2/26/03	SP5NSM2/26/03	SP2NSM2/26/03	SP3NSM2/26/03	SP4NSM2/26/03	NSM-Tank 1 bottom
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water
Sample Type:	Baseline	Baseline	Select Target	Select Target	Select Target	Select Target
Total Metals (ug/L)						
Al						
Sb						
As						
Be						
Cd						
Ca	92600.00	nt	93900.00	93800.00	92800.00	94300.00
Cr						
Cu						
Fe	3280.00		667.00	781.00	1390.00	2010.00
Pb						
Mg	40600.00		40000.00	40300.00	40600.00	41100.00
Mn	643.00		275.00	353.00	598.00	618.00
Hg						
Ni						
K						
Se						
Si						
Ag						
Na						
Ti						
Zn	7010.00		2610.00	4330.00	6240.00	6800.00
Acidity (mg/l)						
Alkalinity (mg/l)						
Ammonia (mg/l)						
Chloride (mg/l)						
Fluoride (mg/l)						
Nitrate/Nitrite-N						
Nitorgen Kjeldahl (mg/l)						
Dis Orthophosphate (mg/l)	<0.05		1.25	0.54	0.05	
Total Phosphorus (mg/l)						
Total Dissolved Phosphorus (mg/l)						
Sulfate (mg/l)						
Sulfide (mg/l)	Note: This sampling event was performed when the apatite treatment system was partially plugged. This data reflects the period between November 11th, 2002 and Feb. 24, 2003.					
Total Coliform Bacteria, cnt/100ml						>1**
Fecal Coliform, Absent/Present						absent**
**** Coliform sample location at Port 1 not a Flum**						

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results						
FLOW ANALYSIS AT NS ADIT						
60 DEG. TRAP. FLUME READING (FT)	0.35					
FLUME FLOW (gpm)	43.63					
Sampling Month	March 2003 - Target Sampling Results					
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream
Sample Date:	3/19/2003	3/19/2003	3/19/2003	3/19/2003	3/19/2003	3/19/2003
Sample #:	NSM SP1 031903	NSM SP2 031903	NSM SP3 031903	NSM SP4 031903	NSM SPUS 031903	NSM SPDS 031903
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water
Sample Type:	Target	Target	Target	Target	Target	Target
INFLUENT FLOW AT TANK #1 - 6 IN. TEE (gpm)	21.4					
FLOW (gpm) AT 10 IN. TEE at Sample Port 2		7.76				
FLOW (gpm) AT 10 IN. TEE at Sample Port 3			9.56			
FLOW (gpm) AT 10 IN. TEE at Sample Port 4				4.14		
TOTAL EFFLUENT FLOW FROM TANKS #2, #3, #4 (gpm)					21.4	
Field Analysis						
pH:	6.83	6.58	6.76	6.9	5.62	6.1
Temperature (°C):	9.8	9.6	9.6	9.3	4.8	4.8
Conductivity (µS/cm):	771.00	788.00	778.00	800	55	68
Orp/Eh (mv):	22.60	-55.80	-56.00	-90.7	80.1	60.9
Dissolved Oxygen (mg/l):	bad probe	bad probe	bad probe	bad probe	bad probe	bad probe
DO (%)						
Laboratory Analysis:						
Dissolved Metals (ug/l)						
Al						
Sb						
As						
Be						
Cd	0.79 B	0.039 U	0.039 U	0.039 U	2.33 B	2.70 B
Ca	89000	96700	90800	95300	4700 B	6110
Cr						
Cu						
Fe	490	62.4B	17.8 B	116	16.8 B	18.3 B
Pb	0.84 B	1.10 B	0.81 U	1.02 B	2.79 B	2.79 B
Mg	40500	40700	40000	39800	2000 B	2560 B
Mn	664	345	502	203	28.8	35
Hg						
Ni						
K						
Se						
Si						
Ag						
Na						
Ti						
Zn	6170	11.4 B	2490	11.4 B	923	1020

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results						
FLOW ANALYSIS AT NS ADIT						
60 DEG. TRAP. FLUME READING (FT)	0.35					
FLUME FLOW (gpm)	43.63					
Sampling Month	March 2003 - Target Sampling Results					
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream
Sample Date:	3/19/2003	3/19/2003	3/19/2003	3/19/2003	3/19/2003	3/19/2003
Sample #:	NSM SP1 031903	NSM SP2 031903	NSM SP3 031903	NSM SP4 031903	NSM SPUS 031903	NSM SPDS 031903
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water
Sample Type:	Target	Target	Target	Target	Target	Target
Total Metals (ug/L)						
Al						
Sb						
As						
Be						
Cd	0.62 B	0.04 U	0.04 U	0.04 U	3.19 B	13.8
Ca	88300	93200	88300	93500	4780 B	6470
Cr						
Cu						
Fe	1640	93.4 B	91..3 B	105	37.6 B	2700
Pb	8.99	2.21 B	2.73 B	2.16 B	6.48	287
Mg	40000	39400	39500	39300	1950 B	2700 B
Mn	661	332	477	182	28.4	122
Hg						
Ni						
K						
Se						
Si						
Ag						
Na						
Ti						
Zn	6210	1010	2810	462	913	1420
Acidity (mg/l)	<10	<10	<10	<10		
Alkalinity (mg/l)	114	126	121	141		
Ammonia (mg/l)	0.07	0.87	0.38	1.5	<0.05	0.05
Chloride (mg/l)	NS	NS	NS	NS		
Fluoride (mg/l)	NS	NS	NS	NS		
Nitrate/Nitrite-N	<0.05	<0.05	<0.05	<0.05	<0.05	0.08
Nitorgen Kjeldahl (mg/l)	0.17	1.1	0.78	1.7	<0.05	
Dis Orthophosphate (mg/l)	<0.05	2	0.78	2.4	<0.05	<0.05
Total Phosphorus (mg/l)	0.33	2	1.3	2.8	0.39	0.32
Total Dissolved Phosphorus (mg/l)	0.11	2	0.85	2.7	0.1	<0.05
Sulfate (mg/l)	296	294	296	280		
Sulfide (mg/l)	1.6	8.2	3	18.6		
Total Coliform Bacteria, cnt/100ml	<1	TNTC	TNTC	TNTC	<1	67
Fecal Coliform, Absent/Present						
** Coliform sample location at Port 1 not a Flum						

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results									
FLOW ANALYSIS AT NS ADIT									
60 DEG. TRAP. FLUME READING (FT)	0.38								
FLUME FLOW (gpm)	54.2								
Sampling Month	April 2003 - Target Sampling Results								
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Port A	Dup - SP2	Blank
Sample Date:	4/23/2003	4/23/2003	4/23/2003	4/23/2003	4/23/2003	4/23/2003	4/23/2003	4/23/2003	4/23/2003
Sample #:	NSM SP1 042303	NSM SP2 042303	NSM SP3 042303	NSM SP4 042303	NSM SPUS 042303	NSM SPDS 042303	NSM SPA 042303	NSM SP5D 042303	NSM SP5B 042303
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:	Target	Target	Target	Target	Target	Target	Target	Target	Target
INFLUENT FLOW AT TANK #1 - 6 IN. TEE (gpm)	26.7								
FLOW (gpm) AT 10 IN. TEE at Sample Port 2		6.8							
FLOW (gpm) AT 10 IN. TEE at Sample Port 3			18.6						
FLOW (gpm) AT 10 IN. TEE at Sample Port 4				2.6					
TOTAL EFFLUENT FLOW FROM TANKS #2, #3, #4 (gpm)					28				
Field Analysis									
pH:	6.73	6.72	6.72	6.92	4.90	4.73	6.7		
Temperature (°C):	10.0	9.8	9.9	9.7	5.6	5.7	9.9		
Conductivity (µS/cm):	774.00	773.00	773.00	791.00	34.00	47.00	773		
Orp/Eh (mv):	-37.80	-108.30	-75.50	-161.20	122.20	153.70	-67.4		
Dissolved Oxygen (mg/l):	bad probe	bad probe	bad probe	bad probe	bad probe	bad probe	bad probe		
DO (%)									
Laboratory Analysis:									
Dissolved Metals (ug/l)									
Al									
Sb									
As									
Be									
Cd	0.53 B	0.05 U	0.05 U	0.05 U	0.91 B	0.59 B	0.56 B	0.05 U	0.05 U
Ca	82700	89800	87900	93000	3230 B	4340 B	87200	88700	18.1 U
Cr									
Cu									
Fe	518	10.1 U	224	68.4 B	10.1 U	10.1 U	462	12.7 B	10.1 U
Pb	0.63 U	0.67 B	0.63 U	0.90 B	2.0 B	1.8 B	1.3 B	1.3 B	1.5 B
Mg	38500	39800	39700	39400	1130 B	1610 B	39800	39500	34.9 U
Mn	647	399	563	213	6.8 B	12.7 B	693	395	2.4 U
Hg									
Ni									
K									
Se									
Si									
Ag									
Na									
Ti									
Zn	5520	11.7 B	4080	5.3 U	339	419	5900	13.8 B	5.3 U

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results									
FLOW ANALYSIS AT NS ADIT									
60 DEG. TRAP. FLUME READING (FT)	0.38								
FLUME FLOW (gpm)	54.2								
Sampling Month	April 2003 - Target Sampling Results								
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Port A	Dup - SP2	Blank
Sample Date:	4/23/2003	4/23/2003	4/23/2003	4/23/2003	4/23/2003	4/23/2003	4/23/2003	4/23/2003	4/23/2003
Sample #:	NSM SP1 042303	NSM SP2 042303	NSM SP3 042303	NSM SP4 042303	NSM SPUS 042303	NSM SPDS 042303	NSM SPA 042303	NSM SP5D 042303	NSM SP5B 042303
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:	Target	Target	Target	Target	Target	Target	Target	Target	Target
Total Metals (ug/L)									
Al									
Sb									
As									
Be									
Cd	0.80 B	0.05 U	0.41 B	0.05 U	0.94 B	0.84 B	0.84 B	0.05 U	0.09 B
Ca	89500	92700	89000	95100	3970 B	5000 B	86300	89300	39.8 B
Cr									
Cu									
Fe	1540	21.6 B	871	91.0 B	44.0 B	60.5 B	3370	29.2 B	10.1 B
Pb	3.0 B	0.75 U	1.4 B	0.75 U	2.2 B	3.3	4.3	0.75 U	0.75 U
Mg	40300	40900	40400	40500	1110 B	1650 B	39200	39400	34.9 U
Mn	684	419	570	216	8.9 B	14.8 B	679	394	2.4 U
Hg									
Ni									
K									
Se									
Si									
Ag									
Na									
Ti									
Zn	5840	2380	4860	342	576	566	6130	2220	5.3 U
Acidity (mg/l)	< 10	< 10	< 10	< 10					
Alkalinity (mg/l)	116	112	117	142					
Ammonia (mg/l)	<0.05	0.68	0.43	1.5	0.21	<0.05			
Chloride (mg/l)									
Fluoride (mg/l)									
Nitrate/Nitrite-N	0.08	1.1	0.7	0.89	0.06	0.75			
Nitorgen Kjeldahl (mg/l)	0.08	0.75	0.68	1.6	0.35	0.2			
Dis Orthophosphate (mg/l)	<0.05	1.2	0.31	2.5	<0.05	<0.05			
Total Phosphorus (mg/l)	0.17	1.4	0.55	2.4	0.1	0.13			
Total Dissolved Phosphorus (mg/l)	<0.05	1.2	0.41	2.4	<0.05	<0.05			
Sulfate (mg/l)	284	273	274	259					
Sulfide (mg/l)	<0.05	1.6	1.4	14					
Total Coliform Bacteria, cnt/100ml				TNTC	30	27			
Fecal Coliform, Absent/Present									
** Coliform sample location at Port 1 not a Flum									

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)	0.325							
FLUME FLOW (gpm)	34.4							
Sampling Month	**May 2003 - Target Sampling Results**							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup - SP3	Blank
Sample Date:	5/29/2003	5/29/2003	5/29/2003	5/29/2003	5/29/2003	5/29/2003	5/29/2003	5/29/2003
Sample #:	NSM SP1 052903	NSM SP2 052903	NSM SP3 052903	NSM SP4 052903	NSM SPUS 052903	NSM SPDS 052903	NSM SP5D 052903	NSM SP5B 052903
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:	Target	Target	Target	Target	Target	Target		
INFLUENT FLOW AT TANK #1 - 6 IN. TEE (gpm)	30.0							
FLOW (gpm) AT 10 IN. TEE at Sample Port 2		1.69						
FLOW (gpm) AT 10 IN. TEE at Sample Port 3			19.7					
FLOW (gpm) AT 10 IN. TEE at Sample Port 4				9.5				
TOTAL EFFLUENT FLOW FROM TANKS #2, #3, #4 (gpm)				30.89				
Field Analysis								
pH:	6.61	6.11	6.18	6.01	5	4.21		
Temperature (°C):	10.1	10.0	10.0	10.0	8.9	8.7		
Conductivity (µS/cm):	777	787	782	807	28	41		
Orp/Eh (mv):	-14.8	-49.8	-32.2	-41.5	36.4	130.7		
Dissolved Oxygen (mg/l):	6.45	0.69	5.28	0.2	10.27	10.84		
DO (%)								
Laboratory Analysis:								
Dissolved Metals (ug/l)								
Al								
Sb								
As								
Be								
Cd	0.44 B	0.05 U	0.06 B	0.05 U	0.71 B	0.61 B	0.05 U	0.05 U
Ca	88800	93200	90500	97200	2960 B	4150 B	91400	36.4 B
Cr								
Cu								
Fe	621	10.0 U	443	61.0 B	10.1 U	10.1 U	445	10.1 U
Pb	0.63 U	0.63 U	0.63 U	0.63 U	1.4 B	1.7 B	0.63 U	0.63 U
Mg	41100	41600	41800	41500	933 B	1430 B	41800	34.9 U
Mn	652	418	567	200	4.8 B	10.0 B	579	2.4 U
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	5810	1470	4870	5.3 U	238	334	4940	5.3 U

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)	0.325							
FLUME FLOW (gpm)	34.4							
Sampling Month	May 2003 - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup - SP3	Blank
Sample Date:	5/29/2003	5/29/2003	5/29/2003	5/29/2003	5/29/2003	5/29/2003	5/29/2003	5/29/2003
Sample #:	NSM SP1 052903	NSM SP2 052903	NSM SP3 052903	NSM SP4 052903	NSM SPUS 052903	NSM SPDS 052903	NSM SP5D 052903	NSM SP5B 052903
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:	Target	Target	Target	Target	Target	Target		
Total Metals (ug/L)								
Al								
Sb								
As								
Be								
Cd	0.53 B	0.05 U	0.42 B	0.05 U	0.83 B	1.3 B	0.44 B	0.05 B
Ca	91600	95000	90900	96300	3060 B	4280 B	90700	112 B
Cr								
Cu								
Fe	1630	27.4 B	1190	89.7 B	34.8 B	43.1 B	1190	30.5 B
Pb	3.4	1.3 B	2.3 B	1.1 B	3.3	4	2.4 B	1.8 B
Mg	41900	42200	41700	41600	927 B	1480 B	41700	34.9 U
Mn	685	415	567	206	6.2 B	12.2 B	567	2.4 U
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	6060	2660	5120	216	273	362	5140	19.2 B
Acidity (mg/l)	< 10	< 10	< 10	< 10				
Alkalinity (mg/l)	120	124	124	153				
Ammonia (mg/l)	<0.05	0.38	0.2	1.9	<0.05	0.3		
Chloride (mg/l)								
Fluoride (mg/l)								
Nitrate/Nitrite-N	<0.05	1.3	0.47	1.1	<0.05	<0.05		
Nitorgen Kjeldahl (mg/l)	0.19	0.53	0.49	2	0.28	0.35		
Dis Orthophosphate (mg/l)	<0.05	0.93	0.23	3	<0.05	<0.05		
Total Phosphorus (mg/l)	0.49	1.4	0.69	2.6	0.41	0.47		
Total Dissolved Phosphorus (mg/l)	0.17	1.1	0.37	2.6	0.12	0.12		
Sulfate (mg/l)	273	277	268	262				
Sulfide (mg/l)	<0.05	1.1	<0.05	11.1				
Total Coliform Bacteria, cnt/100ml	<1 at flume			150	114	70		
Fecal Coliform, Absent/Present				absent	absent	absent		
**** Coliform sample location at Port 1 not a Flum**								

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)	0.35							
FLUME FLOW (gpm)	43.64							
Sampling Month	June 2003 - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup - SP4	Blank
Sample Date:	6/19/2003	6/19/2003	6/19/2003	6/19/2003	6/19/2003	6/19/2003	6/19/2003	6/19/2003
Sample #:	NSM SP1 052903	NSM SP2 052903	NSM SP3 052903	NSM SP4 052903	NSM SPUS 052903	NSM SPDS 052903	NSM SP5D 052903	NSM SP5B 052903
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:	Target	Target	Target	Target	Target	Target		
INFLUENT FLOW AT TANK #1 - 6 IN. TEE (gpm)	18.172							
FLOW (gpm) AT 10 IN. TEE at Sample Port 2		8.666						
FLOW (gpm) AT 10 IN. TEE at Sample Port 3			6.606					
FLOW (gpm) AT 10 IN. TEE at Sample Port 4				3.033				
TOTAL EFFLUENT FLOW FROM TANKS #2, #3, #4 (gpm)				18.305				
Field Analysis								
pH:	6.1	6.54	6.56	6.05	5.73	5.4		
Temperature (°C):	10.1	10.3	10.6	10.4	11.7	11.5		
Conductivity (µS/cm):	746	750	747	750	39	60		
Orp/Eh (mv):	83.6	-22.8	-28.1	-66.1	129.4	-13.9		
Dissolved Oxygen (mg/l):	6.05	0.3	0.95	0.59	9.63	9.74		
DO (%)	55.6	2.8	8.6	5.1	88.5	89.8		
Laboratory Analysis:								
Dissolved Metals (ug/l)								
Al								
Sb								
As								
Be								
Cd	0.38 B	0.05 U	0.06 B	0.05 U	1.2 B	1.0 B	0.05 U	0.05 U
Ca	95700	95800	98200	101000			101000	40.8 B
Cr								
Cu								
Fe	683	34.2 B	367	166			156	10.2 U
Pb	1.5 B	1.7 B	1.8 B	1.7 B			1.3 B	1.5 B
Mg	41600	41400	42000	41700			41700	58.3 U
Mn	676	269	285	236			233	2.6 U
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	6420	918	1280	13.7 B	413	542	7.2 B	6.2 U

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)	0.35							
FLUME FLOW (gpm)	43.64							
Sampling Month	June 2003 - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup - SP4	Blank
Sample Date:	6/19/2003	6/19/2003	6/19/2003	6/19/2003	6/19/2003	6/19/2003	6/19/2003	6/19/2003
Sample #:	NSM SP1 052903	NSM SP2 052903	NSM SP3 052903	NSM SP4 052903	NSM SPUS 052903	NSM SPDS 052903	NSM SP5D 052903	NSM SP5B 052903
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:	Target	Target	Target	Target	Target	Target		
Total Metals (ug/L)								
Al								
Sb								
As								
Be								
Cd	0.38 B	0.05 U	0.08 B	0.05 U	1.2 B	1.3 B	0.05 U	0.05 U
Ca	87900	93300	91300	96500			95900	20.7 B
Cr								
Cu								
Fe	1430	44.7 B	443	148			154	10.2 U
Pb	2.6 B	2.1 B	2.3 B	2.5 B	5.2	5	1.9 B	2.1 B
Mg	40500	40900	40600	41100			40700	58.3 U
Mn	626	265	270	227			226	2.6 U
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	5970	1680	2290	163**	416	517	7.3**	6.2 U
Acidity (mg/l)	<10	<10	<10	<10				
Alkalinity (mg/l)	120	125	128	141				
Ammonia (mg/l)	<0.05	0.76	0.89	1.5	<0.05	<0.05		
Chloride (mg/l)								
Fluoride (mg/l)								
Nitrate/Nitrite-N	<0.05	1.3	1.1	1.3	<0.05	<0.05		
Nitorgen Kjeldahl (mg/l)	<0.05	0.84	0.84	1.7	<0.05	0.11		
Dis Orthophosphate (mg/l)	<0.05	1.3	1.1	2.3	<0.05	<0.05		
Total Phosphorus (mg/l)	0.17	1.4	1.3	2.4	0.12	<0.05		
Total Dissolved Phosphorus (mg/l)	0.06	1.4	1.2	2.4	0.05	0.07		
Sulfate (mg/l)	282	277	258	254				
Sulfide (mg/l)	<0.05	1.6	1.3	9				
Total Coliform Bacteria, cnt/100ml	2			467	119	314		
Fecal Coliform, Absent/Present								
** Coliform sample location at Port 1 not a Flum								

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)	0.34							
FLUME FLOW (gpm)	40							
Sampling Month	July 2003 - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup - SP1	Blank
Sample Date:	7/28/2003	7/28/2003	7/28/2003	7/28/2003	7/28/2003	7/28/2003	7/28/2003	7/28/2003
Sample #:	NSM SP1 072803	NSM SP2 072803	NSM SP3 072803	NSM SP4 072803	NSM SPUS 072803	NSM SPDS 072803	NSM SP5D 072803	NSM SP5B 072803
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:	Target	Target	Target	Target	Target	Target		
INFLUENT FLOW AT TANK #1 - 6 IN. TEE (gpm)	12.4							
FLOW (gpm) AT 10 IN. TEE at Sample Port 2		7.76						
FLOW (gpm) AT 10 IN. TEE at Sample Port 3			3.5					
FLOW (gpm) AT 10 IN. TEE at Sample Port 4				1.01				
TOTAL EFFLUENT FLOW FROM TANKS #2, #3, #4 (gpm)		12.15						
Field Analysis								
pH:	5.38	6.3	6.62	6.73	4.78	4.08		
Temperature (°C):	10.1	10.2	10.6	10.9	13.6	13.3		
Conductivity (μS/cm):	755	759	756	773	47	81		
Orp/Eh (mv):	116.2	11.91	8.6	-43.1	165.8	157.4		
Dissolved Oxygen (mg/l):	10.84	1.48	4.49	0.56	14.19	12.89		
DO (%)	96.4	13.3	40.5	5.1	136.5	122.9		
Laboratory Analysis:								
Dissolved Metals (ug/l)								
Al								
Sb								
As								
Be								
Cd	0.38 B	0.09 B	0.05 U	0.05 U	1.7 B	0.94 B	0.35 B	0.05 U
Ca	94000	98000	96900	101000			95700	42.4 B
Cr								
Cu								
Fe	689	10.2 U	578	107			707	10.2 U
Pb	1.9 B	2.0 B	1.9 B	2.1 B	3.5	3.2	2.0 B	1.9 B
Mg	42600	43400	43200	42900			43300	58.3 U
Mn	607	262	346	174			615	2.6 U
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	6330	3110	1720	6.2 U	482	685	6420	6.2 U

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)	0.34							
FLUME FLOW (gpm)	40							
Sampling Month	July 2003 - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup - SP1	Blank
Sample Date:	7/28/2003	7/28/2003	7/28/2003	7/28/2003	7/28/2003	7/28/2003	7/28/2003	7/28/2003
Sample #:	NSM SP1 072803	NSM SP2 072803	NSM SP3 072803	NSM SP4 072803	NSM SPUS 072803	NSM SPDS 07280	NSM SP5D 072803	NSM SP5B 072803
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:	Target	Target	Target	Target	Target	Target		
Total Metals (ug/L)								
Al								
Sb								
As								
Be								
Cd	0.46 B	0.05 U	0.19 B	0.05 U	1.7 B	1.6 B	0.44 B	0.06 B
Ca	95700	99800	99300	10500			100000	38.8 B
Cr								
Cu								
Fe	1510	10.2 U	946	110			1580	148
Pb	2.0 B	0.81 B	1.4 B	0.78 U	8	4.7	1.6 B	1.2 B
Mg	42700	43600	43400	43600			44200	58.3 U
Mn	620	274	352	183			655	2.6 U
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	6480	3660	3200	94.2	527	746	6830	8.0 B
Acidity (mg/l)	<10	<10	<10	<10				
Alkalinity (mg/l)	119	122	129	140				
Ammonia (mg/l)	<0.05	0.25	0.94	1.6				
Chloride (mg/l)								
Fluoride (mg/l)								
Nitrate/Nitrite-N	0.09	1.1	0.42	0.49	<0.05	NA		
Nitorgen Kjeldahl (mg/l)	<0.05	0.4	1.0	1.6	<0.05	NA		
Dis Orthophosphate (mg/l)	<0.05	0.72	0.85	2.5	<0.05	<0.05		
Total Phosphorus (mg/l)	0.51	0.82	1.3	2.4	0.37	0.11		
Total Dissolved Phosphorus (mg/l)	0.16	0.83	0.97	2.5	0.1	NA		
Sulfate (mg/l)	296	300	292	286				
Sulfide (mg/l)	<0.05	2.2	3.6	14.1				
Total Coliform Bacteria, cnt/100ml	3.0			162	221	229		
Fecal Coliform, Absent/Present								
**** Coliform sample location at Port 1 not a Flum**								

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)	0.34							
FLUME FLOW (gpm)	40.4							
Sampling Month	August 2003 - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup - SP2	Blank
Sample Date:	8/19/2003	8/19/2003	8/19/2003	8/19/2003	8/19/2003	8/19/2003	8/19/2003	8/19/2003
Sample #:	NSM SP1 081903	NSM SP2 081903	NSM SP3 081903	NSM SP4 081903	NSM SPUS 081903	NSM SPDS 081903	NSM SP5D 081903	NSM SP5B 081903
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:	Target	Target	Target	Target	Target	Target		
INFLUENT FLOW AT TANK #1 - 6 IN. TEE (gpm)	16.7							
FLOW (gpm) AT 10 IN. TEE at Sample Port 2		7.7						
FLOW (gpm) AT 10 IN. TEE at Sample Port 3			7.3					
FLOW (gpm) AT 10 IN. TEE at Sample Port 4				1.2				
TOTAL EFFLUENT FLOW FROM TANKS #2, #3, #4 (gpm)			16.6					
Field Analysis								
pH:	5.33	6.38	6.52	6.25	5.19	4.81	6.37	
Temperature (°C):	10.1	10.2	10.3	11.0	12.8	11.9	10.1	
Conductivity (µS/cm):	753	755	753	768	49	85	755	
Orp/Eh (mv):	25.3	-33.6	-28.2	-36	61.2	88.2	-33.6	
Dissolved Oxygen (mg/l):	9.49	2.04	5.86	0.36	13.07	14.17	2.49	
DO (%)	84.6	18.6	52.6	3.4	129.5	131	20	
Laboratory Analysis:								
Dissolved Metals (ug/l)								
Al								
Sb								
As								
Be								
Cd	0.22	0.05	0.05	0.05	1.6	0.91	0.05	0.05
Ca	90700	93300	91600	97300			92000	39
Cr								
Cu								
Fe	537	10.2	347	80.1			10.2	10.2
Pb	0.66	0.66	0.66	0.69	2.9	1.4	0.66	0.66
Mg	10900	41500	41000	40600			41000	58.3
Mn	581	202	413	165			207	2.6
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	6430	3550	3410	6.2	510	721	3420	6.2

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)	0.34							
FLUME FLOW (gpm)	40.4							
Sampling Month	**August 2003 - Target Sampling Results**							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup - SP2	Blank
Sample Date:	8/19/2003	8/19/2003	8/19/2003	8/19/2003	8/19/2003	8/19/2003	8/19/2003	8/19/2003
Sample #:	NSM SP1 081903	NSM SP2 081903	NSM SP3 081903	NSM SP4 081903	NSM SPUS 081903	NSM SPDS 081903	NSM SP5D 081903	NSM SP5B 081903
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:	Target	Target	Target	Target	Target	Target		
Total Metals (ug/L)								
Al								
Sb								
As								
Be								
Cd	0.26	0.05	0.1	0.05	1.4	0.05	1.5	0.05
Ca	92100	93800	92100	96700			95100	31
Cr								
Cu								
Fe	1290	10.2	817	105			10.2	10.2
Pb	0.71	0.77	0.77	0.66	3.6	0.66	3.7	0.66
Mg	41400	41400	41400	41000			41500	58.3
Mn	591	212	413	162			210	2.6
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	6600	3960	4490	67.8	554	765	3950	6.2
Acidity (mg/l)	10	10	10	10				
Alkalinity (mg/l)	118	117	120	138				
Ammonia (mg/l)	0.05	0.13	0.44	1.7	0.05	0.06		
Chloride (mg/l)								
Fluoride (mg/l)								
Nitrate/Nitrite-N	0.05	0.27	0.05	0.05	0.05	0.05		
Nitorgen Kjeldahl (mg/l)	0.11	0.25	0.52	1.8	0.7	0.06		
Dis Orthophosphate (mg/l)	0.05	0.6	0.44	2.5	0.05	0.05		
Total Phosphorus (mg/l)	0.8	1.5	1.4	2.5	0.51	0.5		
Total Dissolved Phosphorus (mg/l)	0.23	0.84	0.69	2.5	0.14	0.21		
Sulfate (mg/l)	283	297	286	286				
Sulfide (mg/l)	0.5	0.5	1.8	10.6				
Total Coliform Bacteria, cnt/100ml	3			79	251	274		
Fecal Coliform, Absent/Present								
**** Coliform sample location at Port 1 not a Flum**								

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)								
FLUME FLOW (gpm)								
Sampling Month	September 2003 - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup - SP3	Blank
Sample Date:	9/23/2003	9/23/2003	9/23/2003	9/23/2003	9/23/2003	9/23/2003	9/23/2003	9/23/2003
Sample #:	NSM SP1 092303	NSM SP2 092303	NSM SP3 092303	NSM SP4 092303	NSM SPUS 092303	NSM SPDS 092303	NSM SP5D 092303	NSM SP5B 092303
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:	Target	Target	Target	Target	Target	Target		
INFLUENT FLOW AT TANK #1 - 6 IN. TEE (gpm)	13.77							
FLOW (gpm) AT 10 IN. TEE at Sample Port 2		5.8						
FLOW (gpm) AT 10 IN. TEE at Sample Port 3			7.76					
FLOW (gpm) AT 10 IN. TEE at Sample Port 4				1.01				
TOTAL EFFLUENT FLOW FROM TANKS #2, #3, #4 (gpm)				14.62				
Field Analysis								
pH:	6.4	6.61	6.5	6.74	6.09	5.7		
Temperature (°C):	10.0	10.0	10.0	10.3	9.0	8.7		
Conductivity (µS/cm):	817	823	820	837	52	92		
Orp/Eh (mv):	42.7	17	31.1	-44.7	45.4	43.4		
Dissolved Oxygen (mg/l):	6.09	0.87	4.11	0.33	10.23	10.21		
DO (%)	54.4	7.7	36.5	2.8	88.5	87.7		
Laboratory Analysis:								
Dissolved Metals (ug/l)								
Al								
Sb								
As								
Be								
Cd	0.41	0.05	0.08	0.07	1.5	1.1	0.05	0.05
Ca	96100	101000	99500	106000			99500	25.3
Cr								
Cu								
Fe	595	10.2	369	87.1			373	10.2
Pb	0.78	0.78	0.78	0.78	2.6	1.5	0.78	0.78
Mg	42300	42900	43000	43200			42600	58.3
Mn	602	164	447	160			477	2.6
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	7160	3920	4770	10	519	792	4920	6.2

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)								
FLUME FLOW (gpm)								
Sampling Month	September 2003 - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup - SP3	Blank
Sample Date:	9/23/2003	9/23/2003	9/23/2003	9/23/2003	9/23/2003	9/23/2003	9/23/2003	9/23/2003
Sample #:	NSM SP1 092303	NSM SP2 092303	NSM SP3 092303	NSM SP4 092303	NSM SPUS 092303	NSM SPDS 092303	NSM SP5D 092303	NSM SP5B 092303
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:	Target	Target	Target	Target	Target	Target		
Total Metals (ug/L)								
Al								
Sb								
As								
Be								
Cd	0.4	0.05	0.34	0.08	1.5	1.6	0.27	0.05
Ca	99800	102000	100000	104000			100000	26.4
Cr								
Cu								
Fe	1490	10.2	1030	97.5			1060	10.2
Pb	1.39	0.78	0.78	0.78	4.9	3.6	0.78	0.78
Mg	43000	43300	43100	43100			42700	58.3
Mn	633	163	489	157			494	2.6
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	7540	4390	5910	89.5	554	808	5940	9.9
Acidity (mg/l)	< 10	< 10	< 10	< 10				
Alkalinity (mg/l)	118	117	120	136				
Ammonia (mg/l)	<0.05	0.14	0.27	1.63	<0.05	<0.05		
Chloride (mg/l)								
Fluoride (mg/l)								
Nitrate/Nitrite-N	0.07	0.38	0.09	0.89	<0.05	<0.05		
Nitorgen Kjeldahl (mg/l)	<0.05	0.18	0.29	1.64	<0.05	<0.05		
Dis Orthophosphate (mg/l)	<0.05	0.62	0.26	2.13	<0.05	<0.05		
Total Phosphorus (mg/l)	2.32	2.2	1.77	2.39	5.8	0.94		
Total Dissolved Phosphorus (mg/l)	1.42	2.26	1.5	2.35	0.75	0.69		
Sulfate (mg/l)	325	331	338	331				
Sulfide (mg/l)	<0.5	<0.5	<0.5	15.33				
Total Coliform Bacteria, cnt/100ml	1			63	148	135		
Fecal Coliform, Absent/Present								
** Coliform sample location at Port 1 not a Flum								

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results									
FLOW ANALYSIS AT NS ADIT									
60 DEG. TRAP. FLUME READING (FT)									
FLUME FLOW (gpm)									
Sampling Month	**October 2003 - Baseline Sampling Results**								
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup - SP1	SP -A	Blank
Sample Date:	10/21/2003	10/21/2003	10/21/2003	10/21/2003	10/21/2003	10/21/2003	10/21/2003	10/21/2003	10/21/2003
Sample #:	NSM SP1 102103	NSM SP2 102103	NSM SP3 102103	NSM SP4 102103	NSM SPUS 102103	NSM SPDS 102103	NSM SP5D 102103	NSMSPA102103	NSM SP5B 102103
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
INFLUENT FLOW AT TANK #1 - 6 IN. TEE (gpm)	9.8								
FLOW (gpm) AT 10 IN. TEE at Sample Port 2		0.8							
FLOW (gpm) AT 10 IN. TEE at Sample Port 3			7.7						
FLOW (gpm) AT 10 IN. TEE at Sample Port 4				1.2					
TOTAL EFFLUENT FLOW FROM TANKS #2, #3, #4 (gpm)				9.7					
Field Analysis									
pH:	6.56	6.52	6.5	6.55	6.58	6.46		6.67	
Temperature (°C):	9.9	9.9	9.9	9.9	9.0	9.1		9.9	
Conductivity (μS/cm):	842	842	841	851	57	97		840	
Orp/Eh (mv):	-24.5	-19.5	-24.4	-102	-18	26.9		-22.5	
Dissolved Oxygen (mg/l):	6.5	1.2	5.87	0.51	10.4	10.3		6.21	
DO (%)								54.8	
Laboratory Analysis:									
Dissolved Metals (ug/l)									
Al	31.1	31.1	35.6	33.8	47.7	31.1	31.1		31.1
Sb	39.9	39.9	39.9	39.9			39.9		39.9
As	0.73	0.56	0.5	0.5			0.62		0.5
Be	1.7	1.7	1.7	1.7			1.7		1.7
Cd	0.46	0.04	0.04	0.04	1.7	1.4	0.46		0.08
Ca	103000	104000	103000	111000			103000		13.7
Cr	8.8	8.8	8.8	8.8			8.8		8.8
Cu	1.4	1.4	1.7	1.4			1.4		1.4
Fe	758	84.8	432	106			762	642	9
Pb	2.1	1.8	1.4	1.1	3.1	3	1.5		2.1
Mg	44300	43700	44100	44900			44000		54.2
Mn	640	162	504	161			643	628	3
Hg	0.11	0.11	0.11	0.11			0.11		0.11
Ni	22.1	22.1	22.1	22.1			22.1		22.1
K	593	599	582	613			592		21.1
Se	1.2	1.2	1.2	1.2			1.2		1.2
Si	7720	7590	7650	7810	4170	4330	7680		48.8
Ag	0.31	0.31	0.31	0.31			0.31		0.31
Na	7760	7660	7740	7980			7740		4
Ti	1.8	1.8	1.8	1.8			1.8		1.8
Zn	7780	3920	5820	6.7	565	842	7790	7670	10

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Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results									
FLOW ANALYSIS AT NS ADIT									
60 DEG. TRAP. FLUME READING (FT)									
FLUME FLOW (gpm)									
Sampling Month	October 2003 - Baseline Sampling Results								
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup - SP1	SP -A	Blank
Sample Date:	10/21/2003	10/21/2003	10/21/2003	10/21/2003	10/21/2003	10/21/2003	10/21/2003	10/21/2003	10/21/2003
Sample #:	NSM SP1 102103	NSM SP2 102103	NSM SP3 102103	NSM SP4 102103	NSM SPUS 102103	NSM SPDS 102103	NSM SP5D 102103	NSMSPA102103	NSM SP5B 102103
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
Total Metals (ug/L)									
Al	31.1	31.1	31.7	31.1	31.1	31.1	31.1		31.1
Sb	39.9	39.9	39.9	39.9			39.9		39.9
As	0.78	0.5	0.5	0.5			0.86		0.5
Be	1.7	1.7	1.7	1.7			1.7		1.7
Cd	0.38	0.04	0.47	0.04	1.6	1.8	0.39		0.04
Ca	103000	103000	102000	107000			103000		12.3
Cr	8.8	8.8	8.8	8.8			8.8		8.8
Cu	1.4	1.4	1.4	1.4			1.4		1.4
Fe	1490	105	1120	111			1490	1590	9
Pb	1.3	0.85	1.4	0.78	3.3	5.3	1.5		0.93
Mg	44000	43400	43900	43800			44100		54.2
Mn	637	161	487	150			643	641	3
Hg	0.11	0.11	0.11	0.11			0.11		0.11
Ni	22.1	22.1	22.1	22.1			22.1		22.1
K	584	603	594	615			582		21.1
Se	1.2	1.2	1.2	1.2			1.2		1.2
Si	7730	7500	7620	7590	4260	4440	7750		36.7
Ag	0.31	0.31	0.31	0.31			0.31		0.31
Na	7750	8200	7750	7940			7700		4
Ti	1.8	1.8	1.8	1.8			1.8		1.8
Zn	7810	4350	6220	84.1	600	909	7850	7880	6.7
Acidity (mg/l)	< 10	< 10	< 10	< 10					
Alkalinity (mg/l)	118	122	118	140					
Ammonia (mg/l)	0.05	0.25	0.3	1.5	<0.05	0.05			
Chloride (mg/l)	<5	<5	<5	<5					
Fluoride (mg/l)	<0.5	<0.5	<0.5	<0.5					
Nitrate/Nitrite-N	0.05	0.31	0.08	<0.05	<0.05	<0.05			
Nitorgen Kjeldahl (mg/l)	0.08	0.34	0.3	1.6	0.1	0.1			
Dis Orthophosphate (mg/l)	<0.05	0.65	0.23	2.3	<0.05	<0.05			
Total Phosphorus (mg/l)	2.17	2.7	2	4	2.1	2.1			
Total Dissolved Phosphorus (mg/l)	2.17	2.7	0.56	2.5	0.19	0.19			
Sulfate (mg/l)	305	309	307	295					
Sulfide (mg/l)	<0.5	1.9	1.9	10.9					
Total Coliform Bacteria, cnt/100ml	<1			55	168	187			
Fecal Coliform, Absent/Present									
** Coliform sample location at Port 1 not a Flum									

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)								
FLUME FLOW (gpm)								
Sampling Month	**November - Target Sampling Results**							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup = SP4	Blank
Sample Date:	11/25/2003	11/25/2003	11/25/2003	11/25/2003	11/25/2003	11/25/2003	11/25/2003	11/25/2003
Sample #:	NSM SP1 102103	NSM SP2 112503	NSM SP3 112503	NSM SP4 112503	NSM SPUS 112503	NSM SPDS 112503	NSM SP5D 11250	NSM SP5B 112503
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:								
INFLUENT FLOW AT TANK #1 - 6 IN. TEE (gpm)	17.605							
FLOW (gpm) AT 10 IN. TEE at Sample Port 2		5.85						
FLOW (gpm) AT 10 IN. TEE at Sample Port 3			7.76					
FLOW (gpm) AT 10 IN. TEE at Sample Port 4				4.01				
TOTAL EFFLUENT FLOW FROM TANKS #2, #3, #4 (gpm)				17.62				
Field Analysis								
pH:	6.65	6.56	6.56	6.74	6.1	5.41		
Temperature (°C):	9.7	9.4	9.5	9.1	1.7	1.9		
Conductivity (µS/cm):	818	821	820	826	60	90.1		
Orp/Eh (mv):	-31.6	-27.1	-26.8	-13.5	31.6	36		
Dissolved Oxygen (mg/l):	6.73	0.86	1.83	1.1	12.18	12.5		
DO (%)	59.3	0.7	16	9.4	87.6	90.1		
Laboratory Analysis:								
Dissolved Metals (ug/l)								
Al								
Sb								
As								
Be								
Cd	0.39	0.04	0.04	0.04	2.2	2.3	0.04	0.04
Ca	101000	105000	104000	106000	NR	NR	106000	31.1
Cr								
Cu								
Fe	868	62.4	33.2	74.2	NR	NR	68.7	9
Pb	0.8	0.8	0.8	0.8	3	2.5	0.8	0.8
Mg	43600	43500	43400	43300	NR	NR	43000	54.2
Mn	646	136	172	271	NR	NR	280	3
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	7530	2450	3650	139	843	1050	280	6.9

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)								
FLUME FLOW (gpm)								
Sampling Month	November - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup = SP4	Blank
Sample Date:	11/25/2003	11/25/2003	11/25/2003	11/25/2003	11/25/2003	11/25/2003	11/25/2003	11/25/2003
Sample #:	NSM SP1 102103	NSM SP2 112503	NSM SP3 112503	NSM SP4 112503	NSM SPUS 112503	NSM SPDS 112503	NSM SP5D 11250	NSM SP5B 112503
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:								
Total Metals (ug/L)								
Al								
Sb								
As								
Be								
Cd	0.33	0.04	0.04	0.04	2	2.2	0.04	0.04
Ca	96700	101000	100000	105000	NR	NR	104000	24.4
Cr								
Cu								
Fe	1460	58.8	28	79.8	NR	NR	90.8	9
Pb	0.8	0.8	0.8	0.8	5.4	5.7	0.8	0.8
Mg	41600	42000	41700	42700	NR	NR	41900	54.2
Mn	621	133	166	269	NR	NR	275	3
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	7240	2710	3580	837	820	1010	870	6.9
Acidity (mg/l)	<10	<10	<10	<10				
Alkalinity (mg/l)	120	124	114	124				
Ammonia (mg/l)	0.06	0.33	0.23	0.36	<.05	<.05		
Chloride (mg/l)								
Fluoride (mg/l)								
Nitrate/Nitrite-N	0.18	0.75	0.27	<.05	<.05	<.05		
Nitorgen Kjeldahl (mg/l)	<.05	0.35	0.24	0.41	<.05	<.05		
Dis Orthophosphate (mg/l)	<.05	0.99	0.7	1.5	<.05	<.05		
Total Phosphorus (mg/l)	0.07	1.1	0.85	1.6	0.06	0.05		
Total Dissolved Phosphorus (mg/l)	0.09	1.1	0.88	1.5	0.06	0.07		
Sulfate (mg/l)	295	292	284	291				
Sulfide (mg/l)	<.05	0.83	<.5	4.2				
Total Coliform Bacteria, cnt/100ml	4			60	21	72		
Fecal Coliform, Absent/Present								
**** Coliform sample location at Port 1 not a Flum**								

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)								
FLUME FLOW (gpm)								
Sampling Month	December 2003 - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup = SP2	Blank
Sample Date:	12/22/2003	12/22/2003	12/22/2003	12/22/2003	12/22/2003	12/22/2003	12/22/2003	12/22/2003
Sample #:	NSMSP1122203	NSMSP2122203	NSMSP3122203	NSMSP4122203	NSMSPUS122203	NSMSPDS122203	NSMSP5D122203	NSMSP5B122203
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:								
INFLUENT FLOW AT TANK #1 - 6 IN. TEE (gpm)	15.78							
FLOW (gpm) AT 10 IN. TEE at Sample Port 2		5						
FLOW (gpm) AT 10 IN. TEE at Sample Port 3			9.5					
FLOW (gpm) AT 10 IN. TEE at Sample Port 4				5				
TOTAL EFFLUENT FLOW FROM TANKS #2, #3, #4 (gpm)					19.5			
Field Analysis								
pH:	6.26	6.43	6.49	6.51	5.25	5.15		
Temperature (°C):	9.7	9.2	9.5	9.3	2.6	2.5		
Conductivity (µS/cm):	826	828	825	831	99	69		
Orp/Eh (mv):	28.5	70.5	26.8	9.5	90.5	140.5		
Dissolved Oxygen (mg/l):	7.09	8.77	4.42	0.72	12.35	12.85		
DO (%)	62.5	76.5	38.4	6.5	90.4	94.5		
Laboratory Analysis:								
Dissolved Metals (ug/l)								
Al								
Sb								
As								
Be								
Cd	0.78	0.06	0.06	0.06	2.6	2.7	0.06	0.06
Ca	93200	95300	95000	99900	NR	NR	94800	18.9
Cr								
Cu								
Fe	657	44.1	166	54	NR	NR	32	9
Pb	0.94	0.94	0.94	0.94	2.4	2.1	0.94	0.94
Mg	40900	40600	40700	41200	NR	NR	40600	54.2
Mn	607	93	255	291	NR	NR	95.6	3
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	7120	2280	4890	866	1040	1170	2210	6.7

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Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)								
FLUME FLOW (gpm)								
Sampling Month	**December 2003 - Target Sampling Results**							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup = SP2	Blank
Sample Date:	12/22/2003	12/22/2003	12/22/2003	12/22/2003	12/22/2003	12/22/2003	12/22/2003	12/22/2003
Sample #:	NSMSP1122203	NSMSP2122203	NSMSP3122203	NSMSP4122203	NSMSPUS122203	NSMSPDS122203	NSMSP5D122203	NSMSP5B122203
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:								
Total Metals (ug/L)								
Al								
Sb								
As								
Be								
Cd	0.81	0.06	0.27	0.06	2.7	2.9	0.06	0.06
Ca	96400	98500	96500	102000	NR	NR	98300	195
Cr								
Cu								
Fe	1410	51.7	391	66.2	NR	NR	38	14.1
Pb	6.3	0.94	2	0.94	4.3	5.6	0.94	0.94
Mg	42200	42000	41600	42400	NR	NR	41700	54.2
Mn	634	101	253	297	NR	NR	97.4	3
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	7420	2970	4950	1480	1070	1230	3020	6.7
Acidity (mg/l)	<10	<10	<10	<10				
Alkalinity (mg/l)	112	116	114	117				
Ammonia (mg/l)	0.05	0.32	0.16	0.35	<.05	0.19		
Chloride (mg/l)								
Fluoride (mg/l)								
Nitrate/Nitrite-N	0.06	1.2	0.27	0.61	<.05	0.93		
Nitorgen Kjeldahl (mg/l)	0.08	0.39	0.25	0.45	0.08	0.34		
Dis Orthophosphate (mg/l)	<.05	0.87	0.51	1.3	<.05	<.05		
Total Phosphorus (mg/l)	0.03	1.1	0.6	1.4	0.1	0.1		
Total Dissolved Phosphorus (mg/l)	0.16	1	0.64	1.4	0.08	<.05		
Sulfate (mg/l)	296	296	294	292				
Sulfide (mg/l)	<.05	1.3	0.93	5.1				
Total Coliform Bacteria, cnt/100ml	<1			7	<1	<1		
Fecal Coliform, Absent/Present								
**** Coliform sample location at Port 1 not a Flum**								

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)								
FLUME FLOW (gpm)								
Sampling Month	February 2004 - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup = SP1	Blank
Sample Date:	2/10/2004	2/10/2004	2/10/2004	2/10/2004	2/10/2004	2/10/2004	2/10/2004	2/10/2004
Sample #:	NSMSP1021004	NSMSP2021004	NSMSP3021004	NSMSP4021004	NSMUS021004	NSMDS021004	NSMSP5D021004	NSMSP5B021004
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:								
INFLUENT FLOW AT TANK #1 - 6 IN. TEE (gpm)	9.78							
FLOW (gpm) AT 10 IN. TEE at Sample Port 2		2.1						
FLOW (gpm) AT 10 IN. TEE at Sample Port 3			5.85					
FLOW (gpm) AT 10 IN. TEE at Sample Port 4				2.56				
TOTAL EFFLUENT FLOW FROM TANKS #2, #3, #4 (gpm)					10.51			
Field Analysis								
pH:	6.21	6.43	6.32	6.49	5.86	5.77		
Temperature (°C):	9.3	9.3	9.4	9.1	2.4	2.5		
Conductivity (µS/cm):	784	818	798	808	64	96		
Orp/Eh (mv):	27.3	60.8	29.3	10.6	101.6	150.3		
Dissolved Oxygen (mg/l):	6.32	7.93	4.81	0.74	12.63	12.61		
DO (%)	51.8	63.2	39.6	6.6	88.6	89.3		
Laboratory Analysis:								
Dissolved Metals (ug/l)								
Al								
Sb								
As								
Be								
Cd	1.4	0.04	0.21	0.04	2.5	2.4	1.3	0.04
Ca	91700	97600	93400	96500	NR	NR	90500	20.4
Cr								
Cu								
Fe	749	115	278	52.8	NR	NR	746	15.1
Pb	0.72	0.72	0.72	0.72	2.5	0.72	0.72	0.72
Mg	39000	39400	39000	39000	NR	NR	38500	41.2
Mn	629	132	347	229	NR	NR	619	2.6
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	7060	1210	5150	1280	1040	1270	700	7

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Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)								
FLUME FLOW (gpm)								
Sampling Month	February 2004 - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup = SP1	Blank
Sample Date:	2/10/2004	2/10/2004	2/10/2004	2/10/2004	2/10/2004	2/10/2004	2/10/2004	2/10/2004
Sample #:	NSMSP1021004	NSMSP2021004	NSMSP3021004	NSMSP4021004	NSMUS021004	NSMDS021004	NSMSP5D021004	NSMSP5B021004
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:								
Total Metals (ug/L)								
Al								
Sb								
As								
Be								
Cd	1.6	0.04	0.72	0.04	2.6	2.8	1.4	0.04
Ca	93800	99400	97100	100000	NR	NR	93500	22.9
Cr								
Cu								
Fe	1980	177	1040	66.7	NR	NR	1980	15.1
Pb	13.4	0.72	7.6	0.72	3.8	10	13.1	0.72
Mg	39500	39900	39800	39800	NR	NR	39500	41.2
Mn	648	136	369	241	NR	NR	644	2.6
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	7320	2420	5560	1880	1090	1380	7270	7
Acidity (mg/l)	<10	<10	<10	<10				
Alkalinity (mg/l)	112	119	116	122				
Ammonia (mg/l)	<.05	0.75	0.19	0.36	<.05	<.05		
Chloride (mg/l)								
Fluoride (mg/l)								
Nitrate/Nitrite-N	<.05	0.07	0.13	0.13	<.05	<.05		
Nitorgen Kjeldahl (mg/l)	0.1	0.8	0.23	0.44	0.13	0.11		
Dis Orthophosphate (mg/l)	0.05	1.1	0.46	1.3	<.05	<.05		
Total Phosphorus (mg/l)	0.05	1.1	0.42	1.4	0.13	0.06		
Total Dissolved Phosphorus (mg/l)	0.06	1.1	0.44	1.2	0.07	<.05		
Sulfate (mg/l)	269	265	266	272				
Sulfide (mg/l)	0.5	1.5	0.67	0.87				
Total Coliform Bacteria, cnt/100ml	<1			4	4	<1		
Fecal Coliform, Absent/Present								
**** Coliform sample location at Port 1 not a Flum**								

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)								
FLUME FLOW (gpm)								
Sampling Month	March 2004 - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup = SP4	Blank
Sample Date:	3/9/2004	3/9/2004	3/9/2004	3/9/2004	3/9/2004	3/9/2004	3/9/2004	3/9/2004
Sample #:	NSMSP1030904	NSMSP2030904	NSMSP3030904	NSMSP4030904	NSMSPUS030904	NSMSPDS030904	NSMSP5D030904	NSMSP5B030904
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:								
INFLUENT FLOW AT TANK #1 - 6 IN. TEE (gpm)	13.77							
FLOW (gpm) AT 10 IN. TEE at Sample Port 2		2.2						
FLOW (gpm) AT 10 IN. TEE at Sample Port 3			9.5					
FLOW (gpm) AT 10 IN. TEE at Sample Port 4				1.3				
TOTAL EFFLUENT FLOW FROM TANKS #2, #3, #4 (gpm)					13			
Field Analysis								
pH:	6.13	6.54	6.44	6.56	5.58	5.66		
Temperature (°C):	9.7	8.7	9.5	9.1	3.8	3.9		
Conductivity (µS/cm):	781	781	779	789	63	80		
Orp/Eh (mv):	91.1	73.5	87.3	88.1	142.6	128.7		
Dissolved Oxygen (mg/l):	6.87	0.45	5.11	1.18	11.82	12.32		
DO (%)	60.5	4.1	45.3	10.5	89.9	94.2		
Laboratory Analysis:								
Dissolved Metals (ug/l)								
Al								
Sb								
As								
Be								
Cd	0.86	0.09	0.33	0.13	2.4	2.5	0.08	0.05
Ca	88900	91300	89600	92000	NR	NR	92800	10
Cr								
Cu								
Fe	348	102	154	52.4	NR	NR	52	15.1
Pb	1.2	1.2	1.2	1.2	3.1	2.9	1.2	1.2
Mg	38700	37500	38400	37700	NR	NR	38000	41.2
Mn	688	127	498	187	NR	NR	187	2.6
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	6310	835	5330	1040	899	990	1070	7

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Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)								
FLUME FLOW (gpm)								
Sampling Month	**March 2004 - Target Sampling Results**							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup = SP4	Blank
Sample Date:	3/9/2004	3/9/2004	3/9/2004	3/9/2004	3/9/2004	3/9/2004	3/9/2004	3/9/2004
Sample #:	NSMSP1030904	NSMSP2030904	NSMSP3030904	NSMSP4030904	NSMSPUS030904	NSMSPDS030904	NSMSP5D030904	NSMSP5B030904
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:								
Total Metals (ug/L)								
Al								
Sb								
As								
Be								
Cd	0.83	0.1	0.63	0.12	2.4	2.4	0.12	0.1
Ca	89700	92200	87400	92000	NR	NR	92700	13.9
Cr								
Cu								
Fe	1750	122	1110	64.5	NR	NR	81	15.1
Pb	5.4	1.2	3.7	1.2	4.4	5.4	1.2	1.2
Mg	38900	38400	38000	37900	NR	NR	38100	41.2
Mn	684	124	480	183	NR	NR	184	2.6
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	6390	1810	5230	1620	866	960	1640	7
Acidity (mg/l)	<10	<10	<10	<10				
Alkalinity (mg/l)	116	132	118	126				
Ammonia (mg/l)	0.08	0.08	0.14	0.44	<.05	0.06		
Chloride (mg/l)								
Fluoride (mg/l)								
Nitrate/Nitrite-N	0.13	0.12	0.17	0.17	0.1	0.37		
Nitorgen Kjeldahl (mg/l)	0.18	0.88	0.22	0.54	0.18	0.17		
Dis Orthophosphate (mg/l)	<.05	1.2	0.26	1.4	<.05	<.05		
Total Phosphorus (mg/l)	0.13	1.1	0.39	1.6	0.14	0.1		
Total Dissolved Phosphorus (mg/l)	0.12	1	0.32	1.5	0.14	0.09		
Sulfate (mg/l)	289	281	291	287				
Sulfide (mg/l)	<.05	1.5	0.67	0.87				
Total Coliform Bacteria, cnt/100ml	3			21	2	5	42	
Fecal Coliform, Absent/Present								
**** Coliform sample location at Port 1 not a Flum**								

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Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)								
FLUME FLOW (gpm)								
Sampling Month	**April 1, 2004 - Target Sampling Results**							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup = SP4	Blank
Sample Date:	4/1/2004	4/1/2004	4/1/2004	4/1/2004	4/1/2004	4/1/2004	4/1/2004	4/1/2004
Sample #:	NSMSP1040104	NSMSP2040104	NSMSP3040104	NSMSP3040104	NSMSPUS040104	NSMSPDS0040104	NSMSP5D040104	NSMSP5B040104
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:								
INFLUENT FLOW AT TANK #1 - 6 IN. TEE (gpm)	15.18							
FLOW (gpm) AT 10 IN. TEE at Sample Port 2		1.33						
FLOW (gpm) AT 10 IN. TEE at Sample Port 3			11.3					
FLOW (gpm) AT 10 IN. TEE at Sample Port 4				2.56				
TOTAL EFFLUENT FLOW FROM TANKS #2, #3, #4 (gpm)					15.19			
Field Analysis								
pH:	6.35	6.36	6.28	6.21	4.82	4.58		
Temperature (^{o}C):	9.8	9.1	9.6	9.4	4.8	4.8		
Conductivity (µS/cm):	768	761	762	772	44	54		
Orp/Eh (mv):	71.8	90.1	80.1	100.5	172.5	170.2		
Dissolved Oxygen (mg/l):	6.52	1.32	5.42	0.43	11.58	11.65		
DO (%)	57.7	11.6	47.6	3.8	90	91		
Laboratory Analysis:								
Dissolved Metals (ug/l)								
Al								
Sb								
As								
Be								
Cd	0.59	0.05	0.26	0.05	1.8	1.9	0.24	0.05
Ca	95000	99800	95600	97800	NR	NR	101	15.1
Cr								
Cu								
Fe	192	164	96	59.5	NR	NR	101	15.1
Pb	1.2	1.2	1.2	1.2	2.4	2.7	1.2	1.2
Mg	40900	41200	40400	40400	NR	NR	41300	41.2
Mn	639	171	502	191	NR	NR	515	2.6
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	7010	524	6070	1310	738	850	6240	7

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Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)								
FLUME FLOW (gpm)								
Sampling Month	April 1, 2004 - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup = SP4	Blank
Sample Date:	4/1/2004	4/1/2004	4/1/2004	4/1/2004	4/1/2004	4/1/2004	4/1/2004	4/1/2004
Sample #:	NSMSP1040104	NSMSP2040104	NSMSP3040104	NSMSP3040104	NSMSPUS040104	NSMSPDS0040104	NSMSP5D040104	NSMSP5B040104
Laboratory:	HKM	HKM	HKM	HKM	HKM	HKM	HKM	HKM
Sample Matrix:	Water	Water	Water	Water	Water	Water	Water	Water
Sample Type:								
Total Metals (ug/L)								
Al								
Sb								
As								
Be								
Cd	0.63	0.05	0.5	0.06	2	2.1	0.48	0.05
Ca	96500	101000	95200	101000	NR	NR	97800	13.9
Cr								
Cu								
Fe	1390	167	1010	70.8	NR	NR	1040	15.1
Pb	2.5	1.2	1.8	1.2	6.7	4.6	1.8	1.2
Mg	40900	41200	40500	41100	NR	NR	40900	41.2
Mn	654	172	497	196	N R	NR	515	2.6
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	7180	1800	6090	1920	782	876	6310	7
Acidity (mg/l)	<10	<10	<10	<10				
Alkalinity (mg/l)	112	122	114	120				
Ammonia (mg/l)	0.08	0.93	0.08	0.47	<.05	0.05		
Chloride (mg/l)								
Fluoride (mg/l)								
Nitrate/Nitrite-N	0.07	<.05	<.05	0.11	<.05			
Nitorgen Kjeldahl (mg/l)	0.06	1.1	0.2	0.54	0.08	<.05		
Dis Orthophosphate (mg/l)	<.05	1.3	0.24	1.4	0.05	<.05		
Total Phosphorus (mg/l)	0.23	2.2	0.49	2.4	0.71	0.62		
Total Dissolved Phosphorus (mg/l)	0.08	2.1	0.45	2.3	0.2	0.15		
Sulfate (mg/l)	291	274	289	281				
Sulfide (mg/l)	<.05	1.9	<.5	0.93				
Total Coliform Bacteria, cnt/100ml	<1			15	<1	17		
Fecal Coliform, Absent/Present								
** Coliform sample location at Port 1 not a Flum								

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Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)								
FLUME FLOW (gpm)								
Sampling Month	**April 29, 2004 - Target Sampling Results**							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup = SP2	Blank
Sample Date:	4/29/2004	4/29/2004	4/29/2004	4/29/2004	4/29/2004	4/29/2004	4/29/2004	4/29/2004
Sample #:	NSMSP1042904	NSMSP2042904	NSMSP3042904	NSMSP4042904	NSMSPUS042904	NSMSPDS042904	NSMSP5D042904	NSMSP6B042904
Laboratory:								
Sample Matrix:								
Sample Type:								
INFLUENT FLOW AT TANK #1 - 6 IN. TEE (gpm)	18							
FLOW (gpm) AT 10 IN. TEE at Sample Port 2		6						
FLOW (gpm) AT 10 IN. TEE at Sample Port 3			10					
FLOW (gpm) AT 10 IN. TEE at Sample Port 4				1.8				
TOTAL EFFLUENT FLOW FROM TANKS #2, #3, #4 (gpm)					17.8			
Field Analysis								
pH:	5.74	5.31	5.26	5.46	4.46	4.12		
Temperature (°C):	10.0	9.8	9.8	9.8	5.9	5.8		
Conductivity (µS/cm):	1012	1017	1023	1027	46	61		
Orp/Eh (mv):	54.3	54.1	62.6	56.6	119.7	122.1		
Dissolved Oxygen (mg/l):	6.38	2.68	2.96	2.12	11.86	11.69		
DO (%)	56.7	23.7	26.3	19	95.7	93.4		
Laboratory Analysis:								
Dissolved Metals (ug/l)								
Al								
Sb								
As								
Be								
Cd	0.41	0.06	0.06	0.06	0.87	0.92	0.06	0.06
Ca	96400	95600	97100	99000	NR	NR	95600	38.3
Cr								
Cu								
Fe	344	12.2	48.9	138	NR	NR	39.5	12.2
Pb	0.54	0.54	0.54	0.54	1.7	1.6	0.54	0.54
Mg	41300	40600	41600	41400	NR	NR	41200	43.3
Mn	605	282	353	250	NR	NR	330	2.3
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	7110	3920	4810	1590	379	453	4540	9.5

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Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)								
FLUME FLOW (gpm)								
Sampling Month	April 29, 2004 - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup = SP2	Blank
Sample Date:	4/29/2004	4/29/2004	4/29/2004	4/29/2004	4/29/2004	4/29/2004	4/29/2004	4/29/2004
Sample #:	NSMSP1042904	NSMSP2042904	NSMSP3042904	NSMSP4042904	NSMSPUS042904	NSMSPDS042904	NSMSP5D042904	NSMSP6B042904
Laboratory:								
Sample Matrix:								
Sample Type:								
Total Metals (ug/L)								
Al								
Sb								
As								
Be								
Cd	0.61	0.06	0.14	0.06	1.1	1.1	0.06	0.06
Ca	95500	96400	95700	101000	NR	NR	97800	24.3
Cr								
Cu								
Fe	1360	12.2	220	187	NR	NR	12.2	12.2
Pb	2.4	1.2	1.3	1.3	3.2	2.9	1	1.2
Mg	41300	40700	41000	41400	NR	NR	41200	43.3
Mn	601	287	342	255	NR	NR	290	2.3
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	7090	4050	4620	1970	387	472	4050	10.2
Acidity (mg/l)	<10	<10	<10	<10				
Alkalinity (mg/l)	114	116	114	120				
Ammonia (mg/l)	0.21	0.24	0.18	0.6	0.12	0.13		
Chloride (mg/l)								
Fluoride (mg/l)								
Nitrate/Nitrite-N	<.05	0.14	0.1	0.09	0.1	1.3		
Nitorgen Kjeldahl (mg/l)	0.35	0.28	0.32	0.81	0.15	0.5		
Dis Orthophosphate (mg/l)	<.05	0.6	0.42	1.4	<.05	<.05		
Total Phosphorus (mg/l)	0.16	0.77	0.57	1.5	<.05	0.08		
Total Dissolved Phosphorus (mg/l)	>.05	0.75	0.56	1.3	<.05	<.05		
Sulfate (mg/l)	317	330	325	321				
Sulfide (mg/l)	<.05	0.59	<.5	<.5				
Total Coliform Bacteria, cnt/100ml	6			<1	13	26		
Fecal Coliform, Absent/Present								
** Coliform sample location at Port 1 not a Flum								

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Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)								
FLUME FLOW (gpm)								
Sampling Month	May 2004 - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup= SP1	Blank
Sample Date:	5/25/2004	5/25/2004	5/25/2004	5/25/2004	5/25/2004	5/25/2004	5/25/2004	5/25/2004
Sample #:	NSMSP1052504	NSMSP2052504	NSMSP3052504	NSMSP4052504	NSMSPUS052504	NSMSPDS052504	NSMSP5D052504	NSMSP6B052504
Laboratory:								
Sample Matrix:								
Sample Type:								
INFLUENT FLOW AT TANK #1 - 6 IN. TEE (gpm)	20.5							
FLOW (gpm) AT 10 IN. TEE at Sample Port 2		12						
FLOW (gpm) AT 10 IN. TEE at Sample Port 3			7.5					
FLOW (gpm) AT 10 IN. TEE at Sample Port 4				0.9				
TOTAL EFFLUENT FLOW FROM TANKS #2, #3, #4 (gpm)					20.4			
Field Analysis								
pH:	5.83	5.77	5.76	6.29	5.34	5.68		
Temperature (^{o}C):	10.0	9.9	9.9	10.1	7.1	7.2		
Conductivity (µS/cm):	83	83	83	84	4	4		
Orp/Eh (mv):	14.4	11.3	3.1	-40	-14.6	173.5		
Dissolved Oxygen (mg/l):	6.47	3.06	5.36	1.82	12.3	11.65		
DO (%)	57.6	27.1	47.4	17.2	98.3	96.6		
Laboratory Analysis:								
Dissolved Metals (ug/l)								
Al								
Sb								
As								
Be								
Cd	0.48	0.1	0.19	0.05	1.4	1.5	0.48	0.05
Ca	85400	93400	94200	96800	NR	NR	85400	13.8
Cr								
Cu								
Fe	274	38.2	95.6	158	NR	NR	274	12.2
Pb	0.74	0.74	0.74	0.74	1.3	1.8	0.74	0.74
Mg	38200	41200	41900	41400	NR	NR	38200	43.3
Mn	502	178	261	169	NR	NR	502	2.3
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	7030	4980	5590	883	575	601	7030	8

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Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)								
FLUME FLOW (gpm)								
Sampling Month	May 2004 - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup= SP1	Blank
Sample Date:	5/25/2004	5/25/2004	5/25/2004	5/25/2004	5/25/2004	5/25/2004	5/25/2004	5/25/2004
Sample #:	NSMSP1052504	NSMSP2052504	NSMSP3052504	NSMSP4052504	NSMSPUS052504	NSMSPDS052504	NSMSP5D052504	NSMSP6B052504
Laboratory:								
Sample Matrix:								
Sample Type:								
Total Metals (ug/L)								
Al								
Sb								
As								
Be								
Cd	0.46	0.06	0.17	0.06	1.4	1.5	0.46	0.06
Ca	94600	98400	97700	103000	NR	NR	94600	10.6
Cr								
Cu								
Fe	1290	20.7	581	207	NR	NR	1290	12.2
Pb	2.4	0.54	0.54	0.54	3.9	4.5	2.4	0.54
Mg	41000	41600	41800	41500	NR	NR	41000	43.3
Mn	555	148	263	177	NR	NR	555	2.3
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	7030	4980	5590	883	575	601	7030	8
Acidity (mg/l)	,10	<10	<10	<10				
Alkalinity (mg/l)	113	113	116	125				
Ammonia (mg/l)	0.12	0.14	0.11	1.1	<.05	0.06		
Chloride (mg/l)								
Fluoride (mg/l)								
Nitrate/Nitrite-N	<.05	0.3	0.17	0.3	<.05	<.05		
Nitorgen Kjeldahl (mg/l)	<.1	0.31	0.36	1.3	0.28	0.15		
Dis Orthophosphate (mg/l)	0.52	0.48	0.4	1.9	<.05	<.05		
Total Phosphorus (mg/l)	0.44	0.45	0.33	1.6	<.05	<.05		
Total Dissolved Phosphorus (mg/l)	0.25	0.4	0.31	1.3	<.05	<.05		
Sulfate (mg/l)	319	330	324	316				
Sulfide (mg/l)	<.5	<.5	<.5	1.5				
Total Coliform Bacteria, cnt/100ml	4			1	64	40		
Fecal Coliform, Absent/Present								
** Coliform sample location at Port 1 not a Flum								

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Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)								
FLUME FLOW (gpm)								
Sampling Month	June 2004 - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup=SP4	Blank
Sample Date:	6/22/2004	6/22/2004	6/22/2004	6/22/2004	6/22/2004	6/22/2004	6/22/2004	6/22/2004
Sample #:	NSMSP1062204	NSMSP2062204	NSMSP3062204	NSMSP4062204	NSMSPUS062204	NSMSPDS062204	NSMSP4D062204	NSMSP6B062204
Laboratory:								
Sample Matrix:								
Sample Type:								
INFLUENT FLOW AT TANK #1 - 6 IN. TEE (gpm)	7.3							
FLOW (gpm) AT 10 IN. TEE at Sample Port 2		3.7						
FLOW (gpm) AT 10 IN. TEE at Sample Port 3			3					
FLOW (gpm) AT 10 IN. TEE at Sample Port 4				1.2				
TOTAL EFFLUENT FLOW FROM TANKS #2, #3, #4 (gpm)					7.9			
Field Analysis								
pH:	6.83	6.69	6.66	6.77	6.47	6.49	6.75	
Temperature (°C):	10.1	10.2	10.2	10.3	10.8	10.6	10.4	
Conductivity (µS/cm):	833	836	835	837	44	60	838	
Orp/Eh (mv):	101.3	131.7	-20.7	-178.4	157.7	178.2	-173.4	
Dissolved Oxygen (mg/l):	5.95	0.46	0.19	0.21	8.67	8.74	0.2	
DO (%)	52	4.3	1.7	1.9	78.3	78.3	2	
Laboratory Analysis:								
Dissolved Metals (ug/l)								
Al								
Sb								
As								
Be								
Cd	0.52	0.06	0.06	0.06	1.5	1.5	0.06	0.06
Ca	92100	91900	93500	91500	NR	NR	91100	55.8
Cr								
Cu								
Fe	310	19.2	94.7	326	NR	NR	326	12.2
Pb	0.54	0.54	0.54	0.54	1.5	1.7	0.54	0.54
Mg	42000	41700	42800	41900	NR	NR	42300	43.3
Mn	608	79	91.5	175	NR	NR	177	2.3
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	7320	3090	2500	13.5	496	614	11.4	8

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)								
FLUME FLOW (gpm)								
Sampling Month	June 2004 - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup=SP4	Blank
Sample Date:	6/22/2004	6/22/2004	6/22/2004	6/22/2004	6/22/2004	6/22/2004	6/22/2004	6/22/2004
Sample #:	NSMSP1062204	NSMSP2062204	NSMSP3062204	NSMSP4062204	NSMSPUS062204	NSMSPDS062204	NSMSP4D062204	NSMSP6B062204
Laboratory:								
Sample Matrix:								
Sample Type:								
Total Metals (ug/L)								
Al								
Sb								
As								
Be								
Cd	0.52	0.06	0.06	0.06	1.5	1.5	0.06	0.06
Ca	91700	94500	94400	90200	NR	NR	90000	8.2
Cr								
Cu								
Fe	1250	21	103	321	NR	NR	348	12.2
Pb	1.9	0.54	0.54	0.54	2.7	3.2	0.54	0.54
Mg	42600	43400	42000	42500	NR	NR	41900	43.3
Mn	608	80.6	94.2	165	NR	NR	174	2.3
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	7270	3200	2500	195	529	625	191	8
Acidity (mg/l)	<10	<10	<10	<10				
Alkalinity (mg/l)	113	117	123	144				
Ammonia (mg/l)	<.05	0.71	0.79	2.4	0.05	0.05		
Chloride (mg/l)								
Fluoride (mg/l)								
Nitrate/Nitrite-N	0.48	0.11	0.05	0.05	<.05	<.05		
Nitorgen Kjeldahl (mg/l)	0.13	0.8	0.92	2.5	0.14	0.18		
Dis Orthophosphate (mg/l)	<.05	0.94	1	2.5	<.05	<.05		
Total Phosphorus (mg/l)	<.05	0.89	1.3	1.1	<.05	<.05		
Total Dissolved Phosphorus (mg/l)	<.05	0.88	1.3	0.95	<.05	<.05		
Sulfate (mg/l)	344	337	337	318				
Sulfide (mg/l)	<.05	<.05	<.5	2.5				
Total Coliform Bacteria, cnt/100ml	<1			3	1	2		
Fecal Coliform, Absent/Present								
** Coliform sample location at Port 1 not a Flum								

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Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)								
FLUME FLOW (gpm)								
Sampling Month	July 2004 - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup=SP1	Blank
Sample Date:	7/26/2004	7/26/2004	7/26/2004	7/26/2004	7/26/2004	7/26/2004	7/26/2004	7/26/2004
Sample #:	NSMSP1072604	NSMSP2072604	NSMSP3072604	NSMSP4072604	NSMSPUS072604	NSMSPDS072604	NSMSP5D072604	NSMSP6B072604
Laboratory:								
Sample Matrix:								
Sample Type:								
INFLUENT FLOW AT TANK #1 - 6 IN. TEE (gpm)	5.1							
FLOW (gpm) AT 10 IN. TEE at Sample Port 2		3.5						
FLOW (gpm) AT 10 IN. TEE at Sample Port 3			1.33					
FLOW (gpm) AT 10 IN. TEE at Sample Port 4				0.74				
TOTAL EFFLUENT FLOW FROM TANKS #2, #3, #4 (gpm)					5.5			
Field Analysis								
pH:	6.76	6.66	6.67	6.72	6.83	6.2	6.82	
Temperature (°C):	10.1	10.6	10.6	11.4	13.1	12.7	10.1	
Conductivity (µS/cm):	829	833	833	833	49	69	830	
Orp/Eh (mv):	54.1	52.7	-44	-117.5	58.6	138	52	
Dissolved Oxygen (mg/l):	7.4	0.17	0.19	0.24	10.39	10.75	7.62	
DO (%)								
Laboratory Analysis:								
Dissolved Metals (ug/l)								
Al								
Sb								
As								
Be								
Cd	0.52	0.03	0.03	0.05	1.7	1.7	0.52	0.03
Ca	97800	100000	101000	100000	NR	NR	98800	21.2
Cr								
Cu								
Fe	738	90.4	343	233	NR	NR	747	10.3
Pb	1.2	1.2	1.2	1.2	2.8	2.8	1.2	1.2
Mg	43200	43200	43500	42900	NR	NR	43700	52.7
Mn	602	89.9	110	169	NR	NR	608	2.2
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	7490	3030	2560	41.1	544	680	7570	9.6

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Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results								
FLOW ANALYSIS AT NS ADIT								
60 DEG. TRAP. FLUME READING (FT)								
FLUME FLOW (gpm)								
Sampling Month	July 2004 - Target Sampling Results							
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup=SP1	Blank
Sample Date:	7/26/2004	7/26/2004	7/26/2004	7/26/2004	7/26/2004	7/26/2004	7/26/2004	7/26/2004
Sample #:	NSMSP1072604	NSMSP2072604	NSMSP3072604	NSMSP4072604	NSMSPUS072604	NSMSPDS072604	NSMSP5D072604	NSMSP6B072604
Laboratory:								
Sample Matrix:								
Sample Type:								
Total Metals (ug/L)								
Al								
Sb								
As								
Be								
Cd	0.61	0.03	0.03	0.03	1.8	1.9	0.59	0.03
Ca	98900	103000	104000	101000	NR	NR	99400	16.1
Cr								
Cu								
Fe	1330	97.9	339	244	NR	NR	99400	16.1
Pb	2	1.2	1.2	1.2	3.7	4.4	1.9	1.2
Mg	43500	43900	44300	43600	NR	NR	44000	52.7
Mn	610	93.4	109	170	NR	NR	611	2.2
Hg								
Ni								
K								
Se								
Si								
Ag								
Na								
Ti								
Zn	7610	3190	2720	19.1	552	706	7620	9.6
Acidity (mg/l)	<10	<10	<10	<10				
Alkalinity (mg/l)	118	125	124	154				
Ammonia (mg/l)	0.12	0.89	1	3.5	0.45	0.14		
Chloride (mg/l)								
Fluoride (mg/l)								
Nitrate/Nitrite-N	<.05	<.05	<.05	<.05	<.05	<.05		
Nitorgen Kjeldahl (mg/l)	0.2	1.1	1.2	5.1	0.39	0.21		
Dis Orthophosphate (mg/l)	0.08	1	1.1	3.1	0.07	<.05		
Total Phosphorus (mg/l)	<.05	1.1	1.1	2.8	<.05	<.05		
Total Dissolved Phosphorus (mg/l)	<.05	1	1.1	2.7	<.05	<.05		
Sulfate (mg/l)	349	342	344	313				
Sulfide (mg/l)	<.05	<.05	<.05	8.2				
Total Coliform Bacteria, cnt/100ml	140			TNTC	TNTC	TNTC		
Fecal Coliform, Absent/Present								
** Coliform sample location at Port 1 not a Flum								

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Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results									
FLOW ANALYSIS AT NS ADIT									
60 DEG. TRAP. FLUME READING (FT)									
FLUME FLOW (gpm)									
Sampling Month	August 2004 - Baseline Sampling Results								
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup=SP4	Blank	SPA
Sample Date:	8/17/2004	8/17/2004	8/17/2004	8/17/2004	8/17/2004	8/17/2004	8/17/2004	8/17/2004	8/17/2004
Sample #:	NSMSP1081704	NSMSP2081704	NSMSP3081704	NSMSP4081704	NSMSPUS081704	NSMSPDS081704	NSMSP5D081704	NSMSP6B081704	NSMSPA081704
Laboratory:									
Sample Matrix:									
Sample Type:									
INFLUENT FLOW AT TANK #1 - 6 IN. TEE (gpm)	7.1								
FLOW (gpm) AT 10 IN. TEE at Sample Port 2		4.14							
FLOW (gpm) AT 10 IN. TEE at Sample Port 3			2.56						
FLOW (gpm) AT 10 IN. TEE at Sample Port 4				0.74					
TOTAL EFFLUENT FLOW FROM TANKS #2, #3, #4 (gpm)					7.4				
Field Analysis									
pH:	6.55	6.66	6.54	6.72	6.45	6.35			6.52
Temperature (°C):	10.1	10.5	10.6	11.7	13.3	13.1			10.6
Conductivity (µS/cm):	822	826	830	825	51	81			825
Orp/Eh (mv):	88.5	43.6	54.7	-156.6	178.8	167.2			96.4
Dissolved Oxygen (mg/l):	6.85	0.13	2.44	0.24	9.44	9.53			7.95
DO (%)	61.3	1.2	22.5	2.3	90.2	90.6			73.3
Laboratory Analysis:									
Dissolved Metals (ug/l)									
Al	26.4	26.4	26.4	26.4			26.4	26.4	
Sb	1.7	3.4	3.6	2.2			1.7	2.7	
As	1.1	0.77	0.95	0.66			0.66	0.66	
Be	0.06	0.06	0.06	0.06			0.06	0.06	
Cd	0.48	0.03	0.03	0.03	2.1	1.8	0.03	0.03	
Ca	103000	105000	105000	105000			106000	38.3	
Cr	9.9	9.9	9.9	9.9			9.9	9.9	
Cu	1.6	1.6	1.6	1.6			1.6	1.7	
Fe	496	30.5	108	160			158	10.3	332
Pb	1.2	1.2	1.2	1.2	3	2.2	1.2	1.2	
Mg	45100	44700	45500	44900			44900	52.7	
Mn	608	71	182	155			156	2.2	577
Hg	0.09	0.09	0.09	0.09			0.09	0.09	
Ni	17.5	21.3	17.5	19.9			17.5	17.5	
K	594	592	591	602			604	16.8	
Se	0.77	0.77	0.77	0.77			0.77	0.77	
Si	7780	7650	7760	7790			7820	5740	
Ag	2.3	2.3	2.3	2.3			2.3	2.3	
Na	7810	7870	7880	7920			7950	7.4	
Ti									
Zn	8000	3700	4400	9.6	602	804	9.6	11.5	7760

MWTP Activity III, Project 39
Treatment Wall Effectiveness

Nevada Stewart Mine Field Sampling Results									
FLOW ANALYSIS AT NS ADIT									
60 DEG. TRAP. FLUME READING (FT)									
FLUME FLOW (gpm)									
Sampling Month	**August 2004 - Baseline Sampling Results**								
Sample Location	Port 1	Port 2	Port 3	Port 4	Upstream	Downstream	Dup=SP4	Blank	SPA
Sample Date:	8/17/2004	8/17/2004	8/17/2004	8/17/2004	8/17/2004	8/17/2004	8/17/2004	8/17/2004	8/17/2004
Sample #:	NSMSP1081704	NSMSP2081704	NSMSP3081704	NSMSP4081704	NSMSPUS081704	NSMSPDS081704	NSMSP5D081704	NSMSP6B081704	NSMSPA081704
Laboratory:									
Sample Matrix:									
Sample Type:									
Total Metals (ug/L)									
Al	26.8	31.6	26.4	26.5			26.4	26.4	
Sb	1.7	1.7	1.7	1.7			1.7	1.7	
As	1.5	1.2	1.1	0.71			0.99	0.91	
Be	0.08	0.06	0.06	0.06			0.06	0.06	
Cd	0.52	0.03	0.1	0.03	2.1	2.7	0.03	0.03	
Ca	101000	103000	102000	102000			103000	33.1	
Cr	9.9	9.9	9.9	9.9			9.9	9.9	
Cu	1.6	1.6	1.6	1.6			1.6	2.3	
Fe	1310	44.2	263	192			201	16.2	1530
Pb	1.2	1.2	1.2	1.2	4.3	4.4	1.2	1.2	
Mg	44300	43800	43500	43300			43700	52.7	
Mn	596	69.8	175	151			153	2.2	564
Hg	0.09	0.09	0.09	0.09			0.09	0.09	
Ni	32.8	22.5	17.5	17.5			17.5	17.5	
K	585	578	567	582			579	16.8	
Se	0.77	0.77	0.77	0.77			0.77	0.77	
Si	7660	7480	7470	7570			7620	5520	
Ag	2.6	3.3	2.3	2.3			2.3	2.3	
Na	7760	7610	7600	7700			7760	7.4	
Ti									
Zn	7840	3790	4270	17.4	581	795	10.9	9.6	7530
Acidity (mg/l)	10	10	10	10					
Alkalinity (mg/l)	118	126	127	149					
Ammonia (mg/l)	0.05	0.44	0.44	2.9	0.11	0.05			
Chloride (mg/l)	5	5	5	5					
Fluoride (mg/l)	0.5	0.5	0.5	0.5					
Nitrate/Nitrite-N	0.05	0.28	0.1	1.7	0.11	0.05			
Nitorgen Kjeldahl (mg/l)	0.15	0.52	0.48	1.7	0.16	0.14			
Dis Orthophosphate (mg/l)	0.05	0.86	0.64	2.9	0.05	0.05			
Total Phosphorus (mg/l)	0.05	0.96	1	4.9	0.05	0.05			
Total Dissolved Phosphorus (mg/l)	0.05	0.9	0.74	4.4	0.05	0.05			
Sulfate (mg/l)	349	351	349	315					
Sulfide (mg/l)	0.5	0.95	0.59	8.6					
Total Coliform Bacteria, cnt/100ml	4			1	TNTC	TNTC			18
Fecal Coliform, Absent/Present									
**** Coliform sample location at Port 1 not a Flum**		TNTC = To Numerous To Count							

Appendix B

EPA Toxicity Testing Reports

App B
nevadastewart 2003 - tox.
doc

Toxicity Test Report

Date: August 12, 2003
From: Mark Smith, SoBran Work Assignment Leader, WA 2-06
To: Jim Lazorchak, EPA Work Assignment Manager
Project: Nevada-Stewart, ID Mine Site Treatment Evaluation Toxicity Tests

Introduction

Water samples from the Nevada-Stewart mine site in Idaho were shipped to SoBran at the U.S. EPA Laboratory in Cincinnati, Ohio. A series of acute aquatic toxicity tests with *Pimephales promelas*, the fathead minnow, and *Ceriodaphnia dubia*, a freshwater invertebrate, were conducted with these samples. The purpose of these tests was to establish the level of toxicity for the discharge from the mine site and to evaluate the effectiveness of the treatment process currently being used at this site.

Definitions

Acute toxicity test: A test method that uses a short exposure period (i.e. 48 hours) to determine the lethal effects of an effluent or receiving water to a selected test organism.

Definitive test: A test that uses a series of effluent or receiving water dilutions to determine the level of acute or short-term chronic toxicity a sample exhibits to a selected test animal.

Profile sample: A sample that is tested using only the 100% (undiluted) test sample.

No Observed Acute Effect Level (NOAEL): That concentration or percent sample in an acute test where the survival of the test animals is determined to not be statistically different from the survival of the control animals. If survival in the lowest test concentration is determined to be statistically different from the control, the data are evaluated to see if the survival in the lowest test concentration is greater than 40%. If it is, the assumption is made that the next dilution in the series would have survival not different from that of the control and this estimated data point is used as the NOAEL.

Fifty Percent Lethal Concentration (LC)50: The estimated concentration of a compound, effluent or receiving water that would cause 50% mortality to the test animals.

Methods

Samples were collected on Tuesday 7/29/03 in one gallon plastic bottles. At least 4L of sample was collected from the mine discharge (SP-1) or the three steps in the treatment process discharge (SP-2, SP-3, SP-4). The sample containers were completely filled, so that no air space was left after they were capped. The samples were placed into a cooler with ice and shipped overnight to the EPA facility in Cincinnati. All coolers were received in good condition with all seals intact, and all samples were in acceptable condition. A total of four water samples were received.

Routine initial chemical parameters (Table 1) were determined and toxicity tests were started on arrival of the samples. The tests with *P. promelas* and *C. dubia* were 48-hr, renewed, acute tests, conducted at 20°C. Each sample was analyzed using both species.

All tests were conducted using moderately hard reconstituted water as the control and dilution water. Test conditions for *C. dubia,* and *P. promelas* are contained in Tables 2, and 3, respectively. Tables 4 and 5 contain the summary data and statistical analysis results for the toxicity tests. Tables 6, 7 and 8 contain summaries of all routine initial and final chemistries.

All LC50 values were determined using the USEPA statistical analysis disk and the Trimmed Spearman-Karber program, version 1.5, which adjusts for control mortality. The Survival No Observed Acute Effect Level (NOAEL) was determined using the USEPA statistical analysis disk and the Dunnett's program, version 1.5.

Results and Discussion

The results from the tests indicate that the treatment system being used to remediate the waste from this mine site is working. The mine discharge sample is SP-1. The LC50 values for this site were 2.21% for *C. dubia* and 26.39% for *P. promleas*. The first segment of the treatment system was SP-2, with LC50 values of 4.07% for *C. dubia* and 70.71% for *P. promelas*. The second stage in the treatment system was SP-3, with an LC50 value of 5.83% for *C. dubia*. Survival of the *P. promelas* in SP-3 was 90% in the 100% non-diluted sample. The *P. promelas* survival in SP-3 was determined to not be statistically different from the control. For sample SP-4, the treatment system discharge, survival in the 100% non-diluted sample was 95% for the *C. dubia* and 100% for the *P. promelas*. Again, the survival of the animals exposed in SP-4 was determined to not be statistically different from the control. The toxicity results for the *C. dubia* tests are found in Table 4. The toxicity results for the *P. promelas* are found in Table 5.

In summary, by the time the mine discharge passed through the treatment system, the NOAEL for the *C. dubia* increased from 1.56% in sample SP-1 to >100% in sample SP-4, Table 4. For the *P. promelas*, the NOAEL increased from 12.5% in SP-1 to >100% in SP-4. The LC50 value for *C. dubia* increased from 2.21% in SP-1 to >100% in SP-4 and the LC50 value for *P. promelas* increased from 26.39% in SP-1 to >100% in SP-4. The results from the toxicity tests with *C. dubia* and *P. promelas* show that the survival of the animals is improved in the treated samples, especially the SP-4 treatment system discharge, when compared to the mine discharge sample.

A set of *C. dubia* and *P. promelas* acute reference toxicity tests were also conducted, with zinc being used as the reference toxicant material. The *C. dubia* LC50 for zinc was 123.3 μg/l. This is in the range of the historical data for this reference toxicant, where the mean for all tests is 193.4 μg/l, with a range of 103 (-2 SD) to 284 (+2 SD). The *P. promelas* LC50 for zinc was 760.6 μg/l. This is in the range of the historical data for this reference toxicant, where the mean for all tests is 722.2 μg/l, with a range of 208 (-2 SD) to 1236 (+2 SD).

TABLE 1. Arrival Chemistries

Sample	Temp (°C)	pH (S.U.)	Alkal. (ppm)	Hard. (ppm)	Cond. (μS/cm)	D.O. (ppm)
SP-1	8.2	6.85	118	600	804	6.3
SP-2	7.5	6.91	120	720	809	4.0
SP-3	7.6	6.95	122	550	806	4.9
SP-4	8.0	7.14	116	600	822	2.0
MHRW	23.5	7.95	60	96	344	8.4

TABLE 2. Standard Test Conditions for *Ceriodaphnia dubia* acute toxicity tests with Superfund and/or Mine Waste samples.

TEST CRITERIA	SPECIFICATIONS
Test Type	Static-renewal
Test Duration	48 hr
Temperature	20°C ± 1°C
Photoperiod	16 hr light/8 hr dark
Test Chamber Size	30 ml (plastic cups)
Test Solution Volume	15 ml
Renewal of Test solution	Daily
Age of Test Organisms	Less than 24-hr-old
Number of Organisms/ per test chamber	5
Number of Replicate Chambers/Conc.	4
Number of Organisms/ Concentration	20
Feeding	none, fed while holding prior to test setup
Dilution Water	Moderately Hard Reconstituted Water
Endpoint	Mortality, LC50
Test Acceptability	≥ 90% survival in the controls

TABLE 3. Standard Test Conditions for *Pimephales promelas* acute toxicity tests with Superfund and/or Mine Waste samples.

TEST CRITERIA	SPECIFICATIONS
Test Type	Static-renewal
Test Duration	48 hr
Temperature	20°C ± 1°C
Photoperiod	16 hr light/8 hr dark
Test Chamber Size	175 ml (plastic cups)
Test Solution Volume	150 ml
Renewal of Test-solution	Daily
Age of Test Organisms	5 days ± 24 hr age range
Number of Organisms/ per test chamber	10
Number of Replicate-Chambers/Conc.	2
Number of Organisms/ Concentration	20
Feeding	Feed newly hatched brine shrimp prior to testing. Do not feed during the test.
Dilution Water	Moderately Hard Reconstituted Water
Endpoint	Mortality, LC50
Test Acceptability	≥90% survival in the controls

TABLE 4. Results from toxicity tests with *Ceriodaphnia dubia.*

Sample	Conc. (%)	Survival	LC50 (%)	Limits	NOAEL (%)	MSD %
SP-1	cont	20/20	2.21	1.72-2.84	1.56	31.93
	0.39%	18/20				
	0.78%	16/20				
	1.56%	14/20				
	3.125%	6/20				
	6.25%	0/20				
SP-2	cont	19/20	4.07	2.95-5.61	0.78	12.53
	0.78%	17/20				
	1.56%	15/20				
	3.125%	11/20				
	6.25%	9/20				
	12.5%	0/20				
SP-3	cont	20/20	5.83	4.39-7.75	1.56	18.97
	1.56%	18/20				
	3.125%	15/20				
	6.25%	7/20				
	12.5%	5/20				
	25%	0/20				
SP-4	cont	19/20	>100%	N/A	>100%	N/A
	100%	19/20				
Zinc	cont	20/20	123.3 ug/l	103.4-	62.5 ug/l	8.35
Reference	31.25 ug/l	20/20		147.1		
Toxicant	62.5 ug/l	19/20				
	125 ug/l	10/20				
	250 ug/l	0/20				
	500 ug/l	1/20				

TABLE 5. Results from toxicity tests with *Pimephales promelas*.

Sample	Conc. (%)	Survival	LC50 (%)	Limits	NOAEL (%)	MSD %
SP-1	cont	19/20	26.39	21.41-	12.5	32.94
	3.125%	18/20		32.54		
	6.25%	18/20				
	12.5%	20/20				
	25%	10/20				
	50%	2/20				
SP-2	cont	20/20	70.71	49.90-	100	33.49
	6.25%	19/20		100.19		
	12.5%	16/20				
	25%	15/20				
	50%	13/20				
	100%	7/20				
SP-3	cont	20/20	>100%	N/A	>100%	N/A
	100%	18/20				
SP-4	cont	18/20	>100%	N/A	>100%	N/A
	100%	20/20				
Zinc	cont	19/20	760.6 ug/l	597.8-	250 ug/l	21.07
Reference	125 ug/l	19/20		967.8		
Toxicant	250 ug/l	15/20				
	500 ug/l	14/20				
	1000 ug/l	11/20				
	2000 ug/l	0/20				

TABLE 6. Initial routine chemistries for *C. dubia,* and *P. promelas* tests.

	Conc.	pH	(SU)	D.O.	(ppm)	Cond.	(μS)	Temp.	(°C)
sxs	(%)	0 hr	24 hr	0 hr	24 hr	0 hr	24 hr	0 hr	24 hr
Cont.	0	8.62	8.14	8.3	8.2	311	312	20.6	20.2
SP-1	0.39	7.73	7.89	7.9	8.4	314	317	20.3	20.1
	0.78	7.74	7.49	7.8	8.4	321	319	20.2	20.2
	1.56	7.70	7.70	7.9	8.3	328	322	20.2	20.2
	3.125	7.83	7.53	8.0	8.4	316	330	20.1	20.1
	6.25	8.07	7.99	8.1	7.9	347	347	20.9	21.0
	12.5	7.73	7.82	8.2	8.2	382	379	20.8	21.1
	25	7.71	7.69	8.3	8.3	444	443	21.1	20.9
	50	7.48	7.50	8.3	8.4	553	555	21.1	20.9
SP-2	0.78	7.93	7.83	7.8	8.5	316	320	20.0	20.7
	1.56	7.93	7.81	7.9	8.5	320	320	20.0	20.8
	3.125	7.93	7.82	7.9	8.5	328	331	20.0	20.8
	6.25	7.92	7.87	8.0	8.5	345	342	19.8	20.8
	12.5	8.39	7.85	8.6	8.2	378	382	21.1	21.0
	25	8.29	7.56	8.4	8.2	441	446	21.0	20.8
	50	7.51	7.51	8.1	7.9	563	449	20.9	21.0
	100	7.19	7.13	7.8	8.2	793	793	20.7	21.0
SP-3	1.56	7.97	8.07	7.7	8.5	320	324	20.0	20.8
	3.125	7.95	8.04	7.7	8.5	328	331	20.1	20.8
	6.25	8.36	7.77	8.1	8.0	345	347	19.9	20.8
	12.5	8.17	7.74	8.2	8.1	383	385	20.9	21.0
	25	7.18	7.25	8.3	7.9	438	448	21.1	20.8
	50	7.00	7.18	8.0	8.1	561	547	21.0	20.9
	100	7.03	7.08	8.0	8.1	788	767	21.1	21.0

TABLE 6. Initial routine chemistries for *C. dubia,* and *P. promelas* tests. (cont'd)

	Conc.	pH	(SU)	D.O.	(ppm)	Cond.	(μS)	Temp.	(°C)
sxs	(%)	0 hr	24 hr	0 hr	24 hr	0 hr	24 hr	0 hr	24 hr
SP-4	100%	7.81	7.52	7.9	7.5	806	805	20.9	21.0
Zinc	31.25	8.50	8.58	8.3	8.1	312	313	21.5	21.0
Ref	62.5	8.48	8.23	8.2	8.3	311	312	21.6	21.0
Tox	125	8.57	8.20	8.3	8.0	312	312	21.4	21.1
ug/l	250	8.40	8.17	8.2	8.0	312	312	21.3	21.1
	500	8.37	8.12	8.3	8.2	313	312	21.2	21.0
	1000	8.30	8.25	8.3	8.1	316	312	21.0	21.0
	2000	8.22	8.00	8.4	8.3	316	315	20.6	20.9

TABLE 7. Final routine chemistries from *C. dubia* tests.

	Conc.	pH	(SU)	D.O.	(ppm)	Cond.	(μS)	Temp.	(°C)
sxs	(%)	24 hr	48 hr	24 hr	48 hr	24 hr	48 hr	24 hr	48 hr
SP-1	cont	7.82	7.89	7.9	8.0	317	317	20.9	20.6
	0.39	7.87	7.73	7.9	8.0	320	317	20.4	20.3
	0.78	7.80	7.83	7.8	7.8	323	320	20.3	20.3
	1.56	7.81	7.86	7.8	7.7	326	323	20.3	20.3
	3.125	7.79	7.71	7.9	7.7	334	332	20.3	20.3
	6.25	8.04	8.20	7.9	7.8	352	347	20.2	20.0
SP-2	cont	8.27	8.00	7.6	8.0	318	317	20.9	20.0
	0.78	7.92	7.80	8.2	8.1	320	320	20.4	20.7
	1.56	7.92	7.86	8.2	8.3	324	320	20.4	20.7
	3.125	7.92	7.89	8.2	8.2	333	332	20.3	20.8
	6.25	8.21	7.97	7.7	8.0	340	348	20.9	20.0
	12.5	8.19	7.96	7.6	7.9	379	372	20.7	20.0
SP-3	cont	8.20	8.10	8.2	7.9	315	316	20.4	20.1
	1.56	8.22	8.03	8.1	7.9	327	325	20.1	20.2
	3.125	8.19	8.00	8.1	7.9	335	332	20.1	20.2
	6.25	8.31	8.08	8.0	7.8	352	351	20.2	20.0
	12.5	8.41	8.05	8.1	7.8	383	384	20.0	19.8
	25	8.08	8.02	8.1	8.0	438	445	20.0	19.8
SP-4	cont	8.06	8.17	7.7	7.9	312	314	21.0	20.1
	100	7.94	7.97	7.9	7.7	772	796	19.8	19.7
Zinc	cont	7.81	7.49	7.7	8.1	314	315	20.3	20.3
Ref	31.25	7.79	7.77	7.7	8.1	318	312	20.2	20.2
Tox	62.5	7.84	7.86	7.8	8.1	315	313	20.1	20.2
ug/l	125	7.72	7.91	7.8	8.0	317	313	20.1	20.2
	250	7.76	7.93	7.8	8.1	317	317	20.1	20.2
	500	7.70	7.95	7.9	8.2	319	313	20.1	20.2

TABLE 8. Final routine chemistries from *P. promelas* toxicity tests.

	Conc.	pH	(SU)	D.O.	(ppm)	Cond.	(μS)	Temp.	(°C)
sxs	(%)	24 hr	48 hr	24 hr	48 hr	24 hr	48 hr	24 hr	48 hr
SP-1	cont	7.79	8.21	8.2	8.0	312	313	20.1	20.7
	3.125	7.77	8.14	8.1	8.0	334	333	20.1	20.3
	6.25	7.75	8.04	7.9	8.0	350	348	20.1	20.1
	12.5	7.85	7.96	7.6	8.0	385	378	20.0	20.0
	25	7.81	7.84	7.8	8.0	448	442	20.0	19.9
	50	7.67	7.71	8.1	8.5	556	553	20.0	19.8
SP-2	cont	8.01	7.97	7.7	7.9	317	316	20.7	20.2
	6.25	7.77	7.81	7.4	7.9	358	351	20.4	20.1
	12.5	7.75	7.78	7.4	8.1	378	381	20.2	20.0
	25	7.36	7.42	7.5	8.0	452	447	20.1	19.8
	50	7.31	7.36	7.4	8.0	560	561	20.3	19.7
	100	7.23	7.30	7.6	8.0	804	793	20.2	19.7
SP-3	cont	7.83	8.03	8.1	8.1	319	314	19.9	20.6
	100	7.56	7.76	7.9	7.8	786	778	20.0	20.4
SP-4	cont	8.04	7.97	7.8	8.4	308	315	20.2	21.0
	100	7.67	7.79	7.7	8.2	801	802	20.3	19.8
Zinc	cont	8.03	8.19	7.7	8.0	315	313	20.0	21.0
Ref	125	7.99	8.15	7.6	8.0	315	313	20.0	20.5
Tox	250	7.94	8.10	7.7	8.1	305	315	20.0	20.2
ug/l	500	7.91	8.07	7.7	8.2	318	314	20.4	20.2
	1000	7.74	8.02	7.7	8.1	321	314	20.3	20.2
	2000	7.75	7.94	8.0	8.3	315	316	20.3	20.2

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Toxicity Test Report

Date:	October 22, 2004
From:	Mark Smith, SoBran Work Assignment Leader, WA 306 (Task 3-A6) Herman Haring, SoBran Aquatic Biologist, WA 306 (Task 3-A6)
To:	Jim Lazorchak, EPA Work Assignment Manager
Project:	Nevada-Stewart, ID Mine Site Treatment Evaluation Toxicity Tests

Introduction

Water samples from the Nevada-Stewart mine site in Idaho were shipped to SoBran at the U.S. EPA Laboratory in Cincinnati, Ohio. A series of acute aquatic toxicity tests with *Pimephales promelas*, the fathead minnow, and *Ceriodaphnia dubia*, a freshwater invertebrate, were conducted with these samples. The purpose of these tests was to establish the level of toxicity for the discharge from the mine site and to evaluate the effectiveness of the treatment process currently being used at this site.

Definitions

Acute toxicity test: A test method that uses a short exposure period (i.e. 48 hours) to determine the lethal effects of an effluent or receiving water to a selected test organism.

Definitive test: A test that uses a series of effluent or receiving water dilutions to determine the level of acute or short-term chronic toxicity a sample exhibits to a selected test animal.

Profile sample: A sample that is tested using only the 100% (undiluted) test sample.

No Observed Acute Effect Level (NOAEL): That concentration or percent sample in an acute test where the survival of the test animals is determined to not be statistically different from the survival of the control animals. If survival in the lowest test concentration is determined to be statistically different from the control, the data are evaluated to see if the survival in the lowest test concentration is greater than 40%. If it is, the assumption is made that the next dilution in the series would have survival not different from that of the control and this estimated data point is used as the NOAEL.

Fifty Percent Lethal Concentration (LC)50: The estimated concentration of a compound, effluent or receiving water that would cause 50% mortality to the test animals.

Methods

Samples were collected on Tuesday 9/28/04 in one gallon cubitainers. At least 4L of sample was collected from the mine discharge (SP-1), the three steps in the treatment process discharge (SP-2, SP-3, SP-4) and samples upstream (US) and downstream (DS) of treatment system. The sample containers were completely filled, so that no air space was left after they were capped. The samples were placed into a cooler with ice and shipped overnight to the EPA facility in Cincinnati. All coolers were received on Wednesday 9/29/04 in good condition with all seals intact, and all samples were in acceptable condition. A total of four water samples were received.

Routine initial chemical parameters (Table 1) were determined and toxicity tests were started on arrival of the samples. The tests with *P. promelas* and *C. dubia* were 48-hr, renewed, acute tests, conducted at 20° C. Each sample was analyzed using both species.

All tests were conducted using moderately hard reconstituted water as the control and dilution water. Test conditions for *C. dubia,* and *P. promelas* are contained in Tables 2, and 3, respectively. Tables 4 and 5 contain the summary data and statistical analysis results for the toxicity tests. Tables 6, 7 and 8 contain summaries of all routine initial and final chemistries.

All LC50 values were determined using the USEPA statistical analysis disk and the Trimmed Spearman-Karber program, version 1.5, which adjusts for control mortality. The Survival No Observed Acute Effect Level (NOAEL) was determined using the USEPA statistical analysis disk and the Dunnett's program, version 1.5.

Results and Discussion

The results from the tests indicate that the treatment system being used to remediate the waste from this mine site is working. The mine discharge sample is SP-1. The LC50 values for this site were 2.19% for *C. dubia* and 9.29% for *P. promleas.* The first segment of the treatment system was SP-2, with LC50 values of 6.27% for *C. dubia* and 25.46% for *P. promelas.* The second stage in the treatment system was SP-3, with an LC50 value of 4.42% for *C. dubia* and 6.93% for *P. promelas*. For sample SP-4, the treatment system discharge, survival in the 100% non-diluted sample was 85% for the *C. dubia* and the LC50 for *P. promelas* was 89.09%. The survival of the *C. dubia* exposed in SP-4 was determined to not be statistically different from that of the control. The Highland Creek sample upstream of the treatment process (US) had LC50 values of 34.15% for *C. dubia* and 32.80% for *P. promelas.* The Highland Creek sample downstream of the treatment process (DS) had LC50 values of 27.74% for *C. dubia* and 35.36% for *P. promelas.* The toxicity results for the *C. dubia* tests are found in Table 4. The toxicity results for the *P. promelas* are found in Table 5.

In summary, by the time the mine discharge passed through the treatment system, the NOAEL for the *C. dubia* increased from 1.56% in sample SP-1 to >100% in sample SP-4, Table 4. For the *P. promelas,* the NOAEL increased from 0% in SP-1 to 50% in SP-4. The LC50 value for *C. dubia* increased from 2.19% in SP-1 to >100% in SP-4 and the LC50 value for *P. promelas* increased from 9.29% in SP-1 to 89.09% in SP-4. The results from the toxicity tests with *C. dubia* and *P. promelas* show that the survival of the animals is improved in the treated samples, especially the SP-4 treatment system discharge, when compared to the mine discharge sample.

Results from the zinc reference toxicant test with each species indicate each performed within acceptable parameters. The results for the *C. dubia* reference toxicant test show an LC50 value of 276.02 ug/l, which compares well to the historical LC50 value of 251.0 ug/l, with limits of 168 to 334 ug/l. The results for the *P. promelas* reference toxicant test show an LC50 value 535.89 ug/l, which compares to the historical value of 718.0 ug/l, with limits of 218 to 1218 ug/l.

Survival data in 2004 with the *C. dubia* remained the same as in 2003. However, an LC50 decrease is observed in the 2004 *P. promelas* data as compared to 2003 data as noted below in Table A. It appears for 2004, the discharge from SP-1 was more toxic to the *P. promelas* and this toxicity is reflected in all samples tested. The upstream and downstream receiving water samples were not collected in 2003, so no year to year comparison can be made.

Table A. 2003 vs. 2004 LC50 values.

	2003		2004	
	C. dubia	*P. promelas*	*C. dubia*	*P. promelas*
SP1	2.21	26.39	2.19	9.29
SP2	4.07	70.71	6.27	25.46
SP3	5.83	90*	4.42	6.93
SP4	95% *	100%*	85% *	89.09

* indicates percent survival in 100%, non-diluted sample (no LC50 values could be generated)

TABLE 1. Arrival Chemistries

Sample	Temp (°C)	pH (S.U.)	Alkal. (ppm)	Hard. (ppm)	Cond. (μS/cm)	D.O. (ppm)
SP-1	3.1	7.15	120	500	867	8.1
SP-2	3.1	7.13	120	480	875	4.2
SP-3	3.0	7.08	126	476	870	5.6
SP-4	2.9	7.17	158	462	871	4.1
US	3.1	7.26	10	42	81	9.8
DS	3.1	7.13	12	50	97	10.2

TABLE 2. Standard Test Conditions for *Ceriodaphnia dubia* acute toxicity tests with Superfund and/or Mine Waste samples.

TEST CRITERIA	SPECIFICATIONS
Test Type	Static-renewal
Test Duration	48 hr
Temperature	20°C ± 1°C
Photoperiod	16 hr light/8 hr dark
Test Chamber Size	30 ml (plastic cups)
Test Solution Volume	15 ml
Renewal of Test solution	Daily
Age of Test Organisms	Less than 24-hr-old
Number of Organisms/ per test chamber	5
Number of Replicate Chambers/Conc.	4
Number of Organisms/ Concentration	20
Feeding	none, fed while holding prior to test setup
Dilution Water	Moderately Hard Reconstituted Water
Endpoint	Mortality, LC50
Test Acceptability	≥ 90% survival in the controls

TABLE 3. Standard Test Conditions for *Pimephales promelas* acute toxicity tests with Superfund and/or Mine Waste samples.

TEST CRITERIA	SPECIFICATIONS
Test Type	Static-renewal
Test Duration	48 hr
Temperature	20°C ± 1°C
Photoperiod	16 hr light/8 hr dark
Test Chamber Size	175 ml (plastic cups)
Test Solution Volume	150 ml
Renewal of Test- solution	Daily
Age of Test Organisms	5 days ± 24 hr age range
Number of Organisms/ per test chamber	10
Number of Replicate- Chambers/Conc.	2
Number of Organisms/ Concentration	20
Feeding	Feed newly hatched brine shrimp prior to testing. Do not feed during the test.
Dilution Water	Moderately Hard Reconstituted Water
Endpoint	Mortality, LC50
Test Acceptability	≥90% survival in the controls

TABLE 4. Results from toxicity tests with *Ceriodaphnia dubia.*

Sample	Conc. (%)	Survival	LC50 (%)	Limits	NOAEL (%)	MSD %
SP-1	cont	18/20	2.19	1.78	1.56	22.33
	0.39%	19/20		2.69		
	0.78%	19/20				
	1.56%	15/20				
	3.125%	3/20				
	6.25%	2/20				
SP-2	cont	20/20	6.27	4.69	3.125	10.34
	0.78%	20/20		8.37		
	1.56%	18/20				
	3.125%	20/20				
	6.25%	9/20				
	12.5%	4/20				
SP-3	cont	18/20	4.42	3.61	1.56	22.47
	1.56%	18/20		5.41		
	3.125%	13/20				
	6.25%	4/20				
	12.5%	1/20				
	25%	0/20				
SP-4	cont	19/20	N/A		100	19.00
	100%	17/20				
US	cont	20/20	34.15	27.79	25	24.79
	6.25%	20/20		41.97		
	12.5%	17/20				
	25%	17/20				
	50%	5/20				
	100%	0/20				

TABLE 4. Results from toxicity tests with *Ceriodaphnia dubia.* Cont'd

Sample	Conc. (%)	Survival	LC50 (%)	Limits	NOAEL (%)	MSD %
DS	cont	20/20	27.74	21.66	12.5	27.95
	6.25%	20/20		35.53		
	12.5%	16/20				
	25%	10/20				
	50%	7/20				
	100%	0/20				
ZINC	MHRW	18/20	276.02	213.46	250	49.66
REFERENCE	31.25	18/20		356.93		
TOXICITY	62.5*	1 /20				
(ug/l)	125	17/20				
	250	10/20				
	500	3/20				

TABLE 5. Results from toxicity tests with *Pimephales promelas*.

Sample	Conc. (%)	Survival	LC50 (%)	Limits	NOAEL (%)	MSD %
SP-1	cont	20/20	9.29	6.83	Cont	7.88
	3.125%	17/20		12.62		
	6.25%	13/20				
	12.5%	9/20				
	25%	0/20				
	50%	0/20				
SP-2	cont	19/20	25.46	20.69	12.5	24.30
	6.25%	19/20		31.34		
	12.5%	18/20				
	25%	7/20				
	50%	4/20				
	100%	0/20				
SP-3	cont	20/20	6.93	5.39	3.125	23.33
	1.56%	20/20		8.93		
	3.125%	17/20				
	6.25%	9/20				
	12.5%	3/20				
	25%	4/20				
	50%	0/20				
	100%	0/20				
SP-4	cont	20/20	89.09	N/A*	50	N/A#
	25%	20/20		N/A*		
	50%	20/20				
	100%	8/20				

N/A* indicates 95% confidence limits are not reliable
N/A# indicates not enough data points to calculate MSD%

TABLE 5. Results from toxicity tests with *Pimephales promelas.* Cont'd

Sample	Conc. (%)	Survival	LC50 (%)	Limits	NOAEL (%)	MSD %
US	cont	18/20	32.80	27.78	25	23.96
	6.25%	19/20		38.74		
	12.5%	17/20				
	25%	16/20				
	50%	2/20				
	100%	0/20				
DS	cont	20/20	35.36	28.49	12.5	12.92
	6.25%	20/20		43.87		
	12.5%	19/20				
	25%	14/20				
	50%	7/20				
	100%	0/20				
ZINC	MHRW	20/20	535.89	437.83	250	8.54
REFERENCE	125	20/20		655.90		
TOXICITY	250	19/20				
(ug/l)	500	10/20				
	1000	3/20				
	2000	0/20				

N/A* indicates 95% confidence limits are not reliable
N/A# indicates not enough data points to calculate MSD%

TABLE 6. Initial routine chemistries for *C. dubia,* and *P. promelas* tests.

	Conc.	pH	(SU)	D.O.	(ppm)	Cond.	(μS)	Temp.	(°C)
sxs	(%)	0 hr	24 hr	0 hr	24 hr	0 hr	24 hr	0 hr	24 hr
SP-1	cont	8.33	8.08	8.2	9.6	303	301	21.4	21.4
	0.39	8.29	8.13	8.3	9.8	305	303	21.4	21.3
	0.78	8.29	8.18	8.4	9.8	306	305	21.4	21.3
	1.56	8.23	8.21	8.4	9.8	312	310	21.4	21.3
	3.125	8.20	8.12	8.6	9.8	323	320	21.3	21.3
	6.25	8.13	8.13	8.6	9.8	342	340	21.3	21.3
	12.5	8.01	7.91	8.6	9.9	381	379	20.8	20.0
	25	7.89	N/A	8.6	N/A	456	N/A	20.9	N/A
	50	7.77	N/A	8.6	N/A	593	N/A	20.8	N/A
SP-2	cont	8.37	8.06	8.0	9.6	303	300	21.1	20.9
	0.78	8.33	8.10	8.4	9.7	306	306	21.1	20.0
	1.56	8.27	8.14	8.5	9.7	312	311	21.0	19.7
	3.125	8.18	8.10	8.6	9.7	323	320	21.1	19.5
	6.25	8.14	8.06	8.7	9.7	344	339	21.0	19.3
	12.5	8.09	7.92	8.8	9.8	386	379	21.0	19.7
	25	7.92	7.71	8.7	9.7	457	455	19.8	20.9
	50	7.77	7.52	8.7	9.5	598	595	19.8	20.6
	100	7.55	N/A	8.5	N/A	855	N/A	19.8	20.8
SP-3	cont	8.28	8.05	8.0	9.7	304	300	21.3	19.7
	1.56	8.22	8.06	8.5	9.8	313	311	21.3	19.2
	3.125	8.14	8.05	8.6	9.8	324	322	21.4	19.5
	6.25	8.14	8.05	8.7	9.8	344	342	21.3	20.5
	12.5	8.04	7.96	8.6	9.8	386	383	21.3	19.6
	25	7.94	7.69	8.8	9.7	451	463	21.4	18.8
	50	7.75	N/A	8.7	N/A	594	N/A	20.3	N/A
	100	7.54	N/A	8.7	N/A	854	N/A	20.3	N/A

TABLE 6. Initial routine chemistries for *C. dubia,* and *P. promelas* tests. (cont'd)

	Conc.	pH	(SU)	D.O.	(ppm)	Cond.	(μS)	Temp.	(°C)
sxs	(%)	0 hr	24 hr	0 hr	24 hr	0 hr	24 hr	0 hr	24 hr
SP-4	cont	8.30	8.24	8.1	9.7	301	301	19.7	20.2
	25	7.43	7.54	8.6	9.5	451	449	20.9	20.5
	50	7.30	7.34	9.0	9.2	594	591	20.9	20.1
	100	7.51	7.26	7.4	6.6	856	860	19.9	20.1
US	cont	8.23	8.02	8.3	9.6	307	301	21.5	21.6
	6.25	8.29	8.22	8.7	9.7	284	287	21.5	21.7
	12.5	8.18	8.22	8.9	9.8	273	273	21.4	21.7
	25	8.13	8.18	9.0	9.8	244	244	21.4	21.5
	50	8.08	8.12	9.1	10.2	189	185	21.5	21.6
	100	7.81	N/A	9.1	N/A	71	N/A	21.5	N/A
DS	cont	8.08	8.08	8.8	9.4	301	301	21.0	21.4
	6.25	8.05	8.17	8.8	9.6	288	288	21.0	21.4
	12.5	7.81	8.23	8.8	9.8	238	276	21.0	21.4
	25	7.80	8.22	8.8	10.0	215	251	21.1	21.4
	50	7.78	8.06	8.8	10.3	128	200	21.1	21.4
	100	7.55	N/A	8.7	N/A	95	N/A	21.0	N/A
Zinc	cont	7.81	8.04	8.3	9.6	304	299	21.1	20.5
Ref	31.25	7.80	8.08	8.4	9.7	301	301	21.1	19.2
Tox	62.5	7.78	8.16	8.5	9.7	301	301	21.2	19.7
ug/l	125	7.84	8.16	8.5	9.8	302	301	21.2	19.8
	250	7.95	8.12	8.7	9.7	302	301	21.2	19.7
	500	7.85	8.13	8.7	9.8	302	301	21.1	19.7
	1000	7.76	8.05	8.7	9.9	303	301	20.0	19.9
	2000	7.67	N/A	8.7	N/A	305	303	19.9	19.8

TABLE 7. Final routine chemistries from *C. dubia* tests.

	Conc.	pH	(SU)	D.O.	(ppm)	Cond.	(μS)	Temp.	(°C)
sxs	(%)	24 hr	48 hr	24 hr	48 hr	24 hr	48 hr	24 hr	48 hr
SP-1	cont	8.26	8.26	9.6	10.2	302	304	19.8	20.6
	0.39	8.30	8.26	9.8	10.1	308	308	19.8	20.7
	0.78	8.33	8.24	9.8	10.2	311	320	19.7	20.6
	1.56	8.27	8.25	9.9	10.2	316	312	19.8	20.6
	3.125	8.18	8.24	9.9	10.2	326	314	19.7	20.7
	6.25	8.17	8.12	9.9	9.8	346	346	19.8	20.7
SP-2	cont	8.29	8.22	9.7	10.1	308	300	19.3	20.7
	0.78	8.29	8.22	9.6	10.2	312	306	19.4	20.8
	1.56	8.27	8.20	9.4	10.2	317	311	19.3	20.7
	3.125	8.27	8.18	9.3	10.3	327	320	19.3	20.6
	6.25	8.23	8.13	9.3	10.3	346	339	19.3	20.8
	12.5	8.16	8.06	8.8	10.3	380	379	19.2	20.5
SP-3	cont	8.32	8.30	9.3	10.1	309	306	21.7	20.7
	1.56	8.31	8.31	9.4	10.2	320	315	21.5	20.8
	3.125	8.25	8.28	9.4	10.2	331	324	21.6	20.6
	6.25	8.27	8.28	9.6	10.3	349	344	21.8	20.7
	12.5	8.12	8.23	9.5	10.3	390	386	21.8	20.7
	25	7.98	8.16	9.2	10.4	448	465	21.8	20.7
SP-4	cont	8.34	8.53	9.3	9.7	306	297	21.2	20.4
	100	8.44	8.42	8.8	9.7	829	820	21.2	20.2
US	cont	8.26	8.21	9.4	9.7	309	302	19.6	20.8
	6.25	8.24	8.14	9.4	9.8	294	297	19.6	20.7
	12.5	8.20	8.14	9.5	9.8	281	279	19.7	20.8
	25	8.18	8.09	9.5	10.0	255	249	19.6	20.8
	50	8.01	8.08	9.2	9.0	198	192	19.6	20.8
	100	7.62	N/A	9.2	N/A	92	N/A	19.6	N/A

TABLE 7. Final routine chemistries from *C. dubia* tests (cont'd).

	Conc.	pH	(SU)	D.O.	(ppm)	Cond.	(μS)	Temp.	(°C)
sxs	(%)	24 hr	48 hr	24 hr	48 hr	24 hr	48 hr	24 hr	48 hr
DS	cont	8.06	8.23	8.0	9..4	306	305	19.8	20.5
	6.25	8.02	8.21	8.2	9.6	294	291	19.8	20.2
	12.5	7.93	8.17	9.3	9.8	281	278	19.7	20.2
	25	7.84	8.02	8.9	10.0	258	252	19.8	20.2
	50	7.77	8.02	9.6	10.3	215	203	19.7	20.3
	100	7.27	N/A	8.2	N/A	111	N/A	19.8	N/A
Zinc	cont	8.33	8.31	9.5	9.9	306	304	20.1	20.4
Ref	31.25	8.32	8.29	9.8	10.1	309	306	20.5	20.3
Tox	62.5	8.32	8.22	9.9	10.3	309	311	20.6	20.3
ug/l	125	8.29	8.23	10.0	10.4	311	304	20.8	20.3
	250	8.28	8.16	10.1	10.5	314	320	21.0	20.3
	500	8.13	8.14	10.1	10.5	305	305	21.0	20.4

TABLE 8. Final routine chemistries from *P. promelas* toxicity tests.

	Conc.	pH	(SU)	D.O.	(ppm)	Cond.	(μS)	Temp.	(°C)
sxs	(%)	24 hr	48 hr	24 hr	48 hr	24 hr	48 hr	24 hr	48 hr
SP-1	cont	8.23	8.27	9.0	10.0	309	306	20.2	20.5
	3.125	8.18	8.18	9.4	10.1	325	323	20.0	20.2
	6.25	8.14	8.14	9.6	10.1	346	341	19.8	20.2
	12.5	8.12	8.05	9.6	10.2	386	381	19.8	20.3
	25	7.98	N/A	9.8	N/A	460	N/A	19.8	N/A
	50	7.98	N/A	9.8	N/A	597	N/A	19.7	N/A
SP-2	cont	8.23	8.18	9.4	10.1	305	315	20.2	20.3
	6.25	8.18	8.21	9.6	10.1	349	343	20.1	20.1
	12.5	8.17	8.16	9.6	10.2	388	391	20.2	20.0
	25	8.10	8.10	9.6	10.3	468	459	20.1	20.1
	50	8.08	8.08	9.7	10.0	605	624	20.0	19.7
	100	8.06	N/A	9.8	N/A	862	N/A	20.0	N/A
SP-3	cont	8.33	8.24	9.6	9.7	303	304	20.3	20.4
	1.56	8.12	7.98	10.0	10.0	316	311	20.0	20.4
	3.125	8.10	8.19	9.8	9.9	325	323	20.0	20.8
	6.25	8.31	8.16	9.7	10.1	344	343	20.1	20.5
	12.5	8.28	8.08	9.7	10.1	388	384	20.0	20.4
	25	8.20	7.99	9.7	9.8	454	461	20.0	20.4
	50	8.14	N/A	9.8	N/A	593	N/A	20.0	N/A
	100	8.02	N/A	9.8	N/A	582	N/A	19.9	N/A
SP-4	cont	8.14	8.24	9.6	10.2	316	312	19.6	N/A
	25	8.05	8.06	9.8	9.3	451	453	20.1	20.9
	50	8.26	8.01	9.8	9.2	595	598	20.0	20.9
	100	8.25	8.33	9.7	10.2	868	872	19.8	N/A

TABLE 8. Final routine chemistries from *P. promelas* toxicity tests (cont'd).

	Conc.	pH	(SU)	D.O.	(ppm)	Cond.	(μS)	Temp.	(°C)
sxs	(%)	24 hr	48 hr	24 hr	48 hr	24 hr	48 hr	24 hr	48 hr
US	cont	8.22	8.25	9.9	9.9	303	305	20.1	20.4
	6.25	8.18	8.29	10.0	10.0	290	288	20.0	20.4
	12.5	8.14	8.23	9.8	10.1	275	288	20.0	20.3
	25	8.10	8.21	9.9	10.2	248	246	20.0	20.4
	50	7.88	8.16	9.9	10.2	191	188	20.0	20.4
	100	7.91	N/A	9.8	N/A	76	N/A	19.9	N/A
DS	cont	N/A	8.20	9.0	10.3	302	305	20.1	20.5
	6.25	N/A	8.21	9.0	10.0	296	291	20.1	20.3
	12.5	8.25	8.17	9.6	10.2	283	270	18.5	20.3
	25	8.23	8.02	9.8	9.9	259	253	17.9	20.3
	50	8.18	8.02	9.8	9.8	212	203	17.6	20.2
	100	8.14	N/A	9.9	N/A	114	N/A	16.2	N/A
Zinc	cont	8.30	8.27	9.7	10.1	315	314	20.5	20.1
Ref	125	8.29	8.28	9.8	10.1	311	304	19.8	20.1
Tox	250	8.27	8.23	9.8	10.1	313	310	19.8	20.3
ug/l	500	8.25	8.20	9.9	10.2	315	307	19.8	20.1
	1000	8.18	8.16	9.8	10.2	326	313	19.6	20.1
	2000	8.06	N/A	10.0	N/A	327	N/A	19.6	N/A

Appendix C

Montana Tech's Final Report
on the Evaluation of Apatite II™ Media
from the Nevada Stewart Mine Apatite Treatment System

App C
Final Mt Tech Report Apatite (2).doc

Removal of Dissolved Metals from Nevada-Stewart Mine Water Using Fish Bone Apatite

Prepared for:

Lynn McCloskey

MSE Technology Applications, Inc.
Mine Waste Technology Program
Activity III, Project 39
Long-Term Monitoring of a Permeable Treatment Wall

Prepared by:

Steve Anderson, Ph.D.
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Montana Tech of The University of Montana

July 2004

Table of Contents

1.0 INTRODUCTION

The goal of this project was to determine the mechanisms responsible for the attenuation of dissolved metals from mining impacted water using fishbone apatite. The research was conducted in conjunction with MSE Technology Application (MSE-TA), Mine Waste Technology Program, Activity III, Project 39, *Long-Term Monitoring of a Permeable Treatment Wall.* MSE-TA in conjunction with the Department of Energy installed a fishbone Apatite Treatment System (ATS) at the Nevada-Stewart Mine site located within the Coeur d'Alene Mining District, six miles south of Pinehurst, Idaho. Fishbone samples for this project were obtained from the ATS in July 2003.

The scope of work for this project included an in-depth literature search focusing on fish-bone apatite used in remediation of contaminated water; digesting and analyzing fish-bone samples using inductively coupled plasma (ICP) to determine the concentrations of contaminants adsorbed to the material; analyzing fish-bone samples using X-Ray Diffraction (XRD) to assist in the identification of the solid materials present in the treatment media; and analyzing fish-bone samples using Scanning Electron Microscopy and energy Dispersive X-Rays (SEM/EDX) to better determine the structure of the materials removed from the contaminated waste stream.

Fish bone samples from the ATS were collected on July 28, 2003. Core samples were collected at varying depths (surface, 8", 16", 24", and 32") from tanks 2, 3, and 4 using a two-inch diameter manual core sampler. The samples were stored in one-quart Glad Ziploc bags, labeled, and refrigerated until use. The samples were digested and prepared according to EPA Test Method 3050B, method two, preparation of sediments, sludges, and soil samples for the analysis of samples by ICP, see Appendix II for the complete method procedures. Samples were then analyzed for Total Dissolved Metals at SVL Analytical, Kellogg, Idaho for the following constituents: calcium, cadmium, iron, magnesium, manganese, lead, and zinc. The bone samples collected were also analyzed using XRD and SEM/EDX. The following sections discuss the methods and results of each element of the scope of work.

2.0 LITERATURE REVIEW

An extensive literature search was conducted using several databases available through the Montana Tech Library. A complete listing of all documents found during the literature search is located in the References section of this report. The following are summaries of selected articles deemed most relevant to the project.

Article #1

Xiaobing, C.; Wright, J.; Conca, J.; Peurrung, L. Effests of pH on Heavy Metal Sorption on Mineral Apatite, Environmental Science and Technology. 1997, 31, 624-631.

Objectives:
Apatite interaction with heavy metals will form insoluble metal phosphates or result in the adsorption of heavy metals on the apatite, reducing aqueous metal concentrations. The effects of pH on solid-phase precipitation were studied.

Test Methods/Procedures:
Sedimentary phosphate rock was ground to a fine powder and passed through a 400 mesh (38µm). Concentrations of lead, cadmium and zinc were prepared from their nitrate salts. Their concentrations are 2.5x $10^{-2,}$ $4.5\text{x}10^{-2}$, and 7.5 $\text{x}10^{-2}$. For each metal a set of 11 solutions with pH 1-12 were prepared. The pH was adjusted using nitric acid and sodium hydroxide.

Single-species sorption tests (SSST): apatite was equilibrated with each of the pH adjusted metal solutions; the samples were then shaken for 24 hours.

Multiple-species sorption tests (MSST): See above
After 24 hours, the samples were centrifuges for 15 minutes then filtered through a .2µm syringe with cellulose acetate membrane. Ph was measured. ICP was used on the determine metal concentrations and solid samples were XRD and SEM.

Results:
Lead: 99.9% reduction in pH range of 3-10.5 and 95.5% reduction at pH of 12.
The primary mechanism of Pb removal was through the dissolution of mineral Apatites and the precipitation of carbonate fluoropyromorphite and hydrocerussite. The solubility of apatites is highly pH dependent with lower solubility at higher pH, which resulted in a drop of dissolved phosphate, carbonate and fluoride in the aqueous system.

Cadmium: Cadmium sorption increased with increase in pH. No crystalline Cadmium phosphates were detected, but otavite and cadmium hydroxide were formed. The dissolution of the apatite is believed to be supplying the carbonate required for the precipitation of otavite. Otavite has high solubility as low pH. Cadmium ions were sorbed by exchange with Ca and Na ions in the lattice of the apatite, but co-precipitation of a surface Ca-Cd phase and surface diffusion may be involved.

Zinc: The sorption behavior of zinc was similar to that of cadmium with minor differences. In the final pH range of 3.3-6.5 the sorption of zinc decreased while at that same pH, the sorption of cadmium increased. When the final pH was above 6.5, nearly all the aqueous zinc was removed (99.9%). The dissolution of the apatite supplied the dissolved phosphate to the aqueous zinc solution, which was followed by the formation of hopeite.

<u>Article #2</u>

Hodson, M.; Jones, E.; Howells, J. Bonemeal Additions as a Remediation Treatment for Metal Contaminated Soil. American Chemical Society. 2000, 34, 3501-3507.

Objectives:

Poorly crystalline apatite could be used to provide a phosphate source that can be used to remediate metal contaminated soils without causing excessive phosphate runoff. Soil was taken from three locations to give a range of metal contamination and pH values. The bone meal used was sieved to a size of 90-500 μm.

Test Methods/Procedures:

Leaching Columns: 200 grams of a 1:50 bonemeal:soil mix were packed into 250 mL columns. The soil was irrigated manually by sprinkling twice a day with a dilute solution similar in composition to that of natural rain. The columns were kept in the dark in a temperature between 18-24 C.

Batch Experiment 1-Predicted Metal Availability: 6 grams of fresh contaminated soil was mixed with 120 mL of artificial rain solution, stirred, and left at room temperature for 7 days. The mixtures were then air-dried. 10 mL of .01 M $CaCl_2$ was shaken with 1 g of sample for 1 hour then centrifuged for 15 minutes at 200 rpm. The solution was filtered than acidified with reagent HNO_3 to a strength of 2.5% HNO_3.

Batch Experiment 2-pH effects: 6 grams of soil was mixed with 30 mL artificial rain, and 6 grams of soil was shaken with 30 mL of sodium hydroxide solution to cause the same pH change as was observed in the bone meal treated soil. After 24 hours, samples were centrifuged and passed through a filter. PH was measured and the solutions were acidified using reagent nitric acid to strength of 2.5% nitric acid.

Scanning Electron Microscopy (SEM): at the end of the leaching column experiment, dry soil and bonemeal:soil mixture was mounted in epoxy resin, polished, and carbon coated.

X-ray Diffraction (XRD):Bonemeal particles were separated from the bulk of the soil by floating them off the soil in water. The remaining material was dried and crushed to a size of <20 μg and mounted on silicon wafer stubs.

Results:

Leachate Columns: reduction of metal concentrations from the columns could have been due to any one or a combination of precipitation of metal phases in response to the pH rise, adsorption of metals onto bone meal particles, and precipitation of metal phosphates.

Batch Experiment 1: Bonemeal treatments generally reduced the concentration of metal ions held on exchange sites and reduced concentrations of some chelatable metals.

Batch Experiment 2: Significant pH rises and metal immobilization was observed in all the bone meal treated soils. Immobilization of metals was not solely due to the change in pH.

SEM/XRD: Lead, Zinc, and Phosphate were observed occurring together within, or on the edge of, reacted bone meal particles. Any newly formed metal is not likely due to the process of substitution because ionic substitution is a very slow process at ambient temperatures and pressures. Metal phosphates formed by precipitation after calcium, phosphate dissolution.

Article #3

Knox, A.S.; Kaplan, D.I.; Adriano, D.C. Apatite and Phillipsite as Sequestering Agents for Metals and Radionuclides. Journal of Environmental Quality. 2003, 32, 515-525.

Objectives:
Determine the influence of apatite and phillipsite additions on contaminant sequestration and plant growth.

Test Methods/Procedures:
Lab Batch Study: a concentration of 50 mg L-1 was placed in 50 mL centrifuge tubes for one week. Suspensions composed of .3 grams of solid and 30 mL of spike solution were shaken for one week, phase separated, and the aqueous phase was analyzed for metal content by ICP and pH.

Greenhouse Bioavailability: Contaminated soil was collected and mixed with apatite and phillipsite at two rates: 25 and 50 g/kg. After 4 weeks of soil equilibration, maize was planted and harvested after 6 weeks of growth.

Results:
Lab Batch Study: The concentration of each element ($Co^{2+,}$ Ba^{2+}, Eu^{3+}, Pb^{2+}, and UO_2^{2+}) in the spike solution was approximately 50mg/L. After one week, apatite reduced aqueous solutions of each metal. A ranking of metals by their apatite Kd values is Eu, Pb, U>Co>Ba. Barium was the only metal that phillipsite removed from the aqueous phase at a greater extent than apatite.

Greenhouse Bioavailability: Amendments were effective at redistributing the Cd, Pb, and Zn into fractions that were more strongly held by the soil.

Article #4

Kos, B.; Lestan, D. Induced Phytoextraction/Soil Washing of Lead Using Biodegradable Chelate and Permeable Barriers. Environmental Science and Technology. 2003, 37, 624-629.

Objectives:
To evaluate enhanced phytoextraction of Pb supported by addition of commonly used chelate EDTA and biodegradable chelates EDDS, combined with in-situ soil washing of Pb using the same chelates and permeable barriers to minimize losses of Pb.

Test Methods/Procedures:
Soil was passed through a 4-mm sieve and EDTA induced Pb plant uptake, and washing and leaching were studied in a soil column experiment. Columns were layered with enriched substrates and apatite. Soils were fertilized and planted with seeds. After the 30-day, the plants were harvested and tested. Hydrogel was added to test the water sorption capacity. The metabolic heat that was generated monitored microbial activity.

Results:
Pb uptake in plants was only .05-.02% of the total Pb in the soil. The use of EDTA and EDDS did increase the plant uptake, but not enough to make it an efficient removal technology. The columns where the chelate was added removed the Pb below the detection limit of the instrument. It is proposed that mechanisms for Pb immobilization are the conversion of Pb to pyromorphite, a poorly soluble Pb phosphate mineral.

Article #5

Laperche, V.; Logan, T.; Gaddam, P.; Traina, S. Effect of Apatite Amendments on Plant Uptake of Lead from Contaminated Soil. American Chemical Society. 1997, 31, 2745-2753.

Objectives:
This study investigates the use of apatite minerals to induce in situ formation of stable lead phosphates in contaminated soil, and determine the impact of apatites on Pb uptake by plants.

Test Methods/Procedures:
The soil used contained approximately 37 026 mg of Pb/kg, along with high concentrations Zn, Cr, Cu, and Cd. Minerals used were in the form of a hydroxylapatite, fluorapatite, chlorapatite and pyroapatite. 100 sudax seeds were germinated and grown in pots containing sand. The only phosphate in the experiment came from the natural and synthetic apatites and hydroxypyromorphite (HP). Pots containing contaminated soil were mixed with phosphate materials and seeds were planted. The roots from the sand experiments and the soil assays were examined using XRD and SEM.

Results:
The total cumulative above ground biomass and root biomass in the sand treatment watered with P nutrient solution was higher than the other treatments watered with P-free nutrient solution. The biomasses of the treatments with apatites were slightly higher than for the treatment with HP. The addition of phosphate to Pb-contaminated soil can immobilize Pb as an identifiable stable form, pyromorphite. Plant uptake of Pb can be reduced using HA or PR.

Article #6

Laperche, V.; Traina, S.; Gaddam, P.; Logan, T. Chemical and Mineralogical Characterizations of Pb in a Contaminated Soil: Reactions with Synthetic Apatite. Environmental Science and Technology. 1996, 30, 3321-3326.

Objectives:
The aim of this study was to further investigate the use of HA as a soil additive with the goal of converting "native" Pb forms to HP.

Test Methods/Procedures:

All of the apatite amendments were made with a synthetic hydroxylapatite. The soil sample was air dried and passed through a 2-mm sieve. Density separation was done using a centrifuge. Whole soil samples and particles >100 um were ground to fine powders. All samples were digested with HF-HCL/HNO_3 . MINEQL + calculations were performed to determine the chemical distribution of all species in solution and the propensity for precipitation of any solids at each pH value encountered in the lab experiments. XRD and SEM were done.

Results:

XRD indicated only two Pb phases, Cerussite and Litharge. High concentrations of Ca, Mg, Pb, and inorganic C were in accordance with the XRD identification of calcite and magnesite. Strong correlations were observed between total organic C content and total Cu, Cd, and Zn soil concentrations.

Pb immobilization with synthetic hydroxylapatite was studied. HA was reacted with PbO (mixture of litharge and massicot). At a pH of 5, a greater quantity of HP formed. Under neutral pH conditions, HP formed as very small needles on the surface of HA. In more acid solutions, larger discrete HP particles formed.

Formation of HP particles in contaminated soil was proven using XRD and SEM. The extent to which this process occurs is dependent upon pH. However, at pH values<8, HP formation appears to be limited by kinetic rather than thermodynamic constraints.

Article #7

Ma, Q.; Traina, S.; Logan, T.; Ryan, J. Effects of Aqueous Al, Cd, Cu, Fe(II), Ni, and Zn on Pb Immobilization by Hydroxyapatite. American Chemical Society. 1994, 28, 1219-1228.

Objectives:

The objective of this study was to test the effectiveness of hydroxyapatite to remove commonly encountered metals of concern including Cu, Ni, Cr(II), Cd, Pb, Hg(II), Zn and Ag(I).

Test Methods/Procedures:

Different concentrations of Pb were reacted with HA in the presence of varying levels of Al, Cd, Cu, Fe(II), Ni, or Zn to test the effects of these metals on Pb immobilization by HA. One-tenth a gram of HA was reacted with 200 mL of solutions containing 24.1, 121, 241, and 482 μmol of Pb/L as $Pb(NO_3)_2$. The suspensions were shaken for 2 hours and filtered. The filtrates were analyzed for total P, Pb, Ca, Cd, Cu, Ni, Zn, Al, Fe(II), and pH. The solid phases were analyzed using XRD and SEM.

XRD: Analyses were conducted using Cu K-α radiation at 35 kV and 20 mA. Measurements were made using a step-scanning technique with a fixed time of $4s/.05^{\circ}2\theta$.
The samples were mounted on a stainless steel stub and coated with Au and Pd for observation.
MINTEQA2—was used to calculate equilibrium distributions and activities of aqueous species using total dissolved Pb, Ca, Al, Cd, Cu, Fe(II), Ni, Zn, NO_3, and PO_4.

Results:
Added metals reduced the effectiveness of Pb immobilization by HA. Nickel had little effect on Pb immobilization by HA. Al, Cd, and Zn caused decreases in Pb immobilization by HA only at the greatest initial Pb concentration and at M/Pb rations greater than 1. Copper and Fe(II) exhibited the greatest inhibition on Pb immobilization. The effectiveness of HA in immobilizing Pb in the presence of the added metals was in the order: Al<Cu<Fe(II)<Cd<Zn<Ni at high initial lead concentrations. In more dilute lead concentrations, the order was Cu<Fe(II)<Cd<Zn<Al<Ni.

Solution pH decreased in the order: Ni<Zn<Cd<Al<Cu<Fe(II). Total P concentrations decreased in the order: Ni<Zn<Cd<Fe(II).

Needle-shaped HP crystals were observed on HA surfaces after reaction with Pb in the presence of Ni, Cd, or Zn, while little to no HP precipitates were visible on HA surfaces in the presence of Cu, Fe(II), or Al.

In general, the effectiveness of HA in removing metals was in the order Al>Zn>Fe(II)>Cd>Cu>Ni; whereas the effectiveness of those metals in inhibiting Pb immobilization by HA was Al>Cu>Fe(II)>Cd>Zn>Ni.

<u>Article #8</u>

Ma, Q.; Logan, T.; Traina, S.; Ryan, J. Effects of NO_3^-, Cl^-, F^-, SO_4^{2-}, and CO_3^{2-} on Pb^{2+} Immobilization by Hydroxyapatite. Environmental Science and Technology. 1994, 28, 408-418.

Objectives:
This study investigates the effects of NO_3^-, Cl^-, F^-, SO_4^{2-}, and CO_3^{2-} on hydroxyapatite- Pb^{2+} interactions.

Test Methods/Procedures:
Different concentrations of Pb^{2+} were reacted with HA in the presence of various levels of NO_3^-, Cl^-, F^-, SO_4^{2-}, and CO_3^{2-} to test the effects of these anions on Pb^{2+} immobilization by HA. .1 g of HA was reacted with 200mL of solution containing 24.1, 121, 241, and 482 μmol of Pb^{2+} /L. The suspensions were shaken and filtered. The solid phases were analyzed using XRD and SEM.

XRD: Analyses were conducted using Cu K-α radiation at 35 kV and 20 mA. Measurements were made using a step-scanning technique with a fixed time of 4s/.05°2θ.
The samples were mounted on a stainless steel stub and coated with Au and Pd for observation.

Results:
Nitrate had little effect on final Pb^{2+} concentrations. The XRD data showed that HP was present together with excess HA. The peak intensities of HP increases with an increase in initial lead

concentrations, indicating more formation of HP at higher lead concentrations, and they did not change with varying nitrate concentrations.
Chloropyromorphite and FP were formed after aqueous PO_4^{3-} reacted with lead in the presence of Cl^- and F^- at pH 3,5,7, and 9. The peak intensities of both CP and FP were highest at pH 3. Phosphate concentrations increased with an increase in initial F concentrations, and they did not change with increasing Cl concentrations. Solution pH decreased with increasing concentrations of both Cl and F.
Sulfate had little effect on final lead concentrations; however, final lead concentrations increased in the presence of CO_3^{2-}, indicating that CO_3^{2-} reduced the effectiveness of HA in immobilizing lead. Glauberite was formed in the presence if SO_4^{2-}. Varying concentrations of sulfate had no effect on the XRD patterns of HP.

Hydroxyapatite was transformed to CP and FP after reaction with aqueous lead in the presence of Cl and F, and to HP in the presence of nitrate, SO_4^{2-}, or CO_3^{2-}. hydroxyapatite dissolution followed by HP, CP, or FP precipitation was the main chemical reaction.

Variations of anion concentrations of nitrate, chlorine, or sulfate had no effect on lead immobilization by HA, whereas F and CO_3^{2-} decreased lead immobilization by HA slightly.

Article #9

Ma, Q.; Traina, S.; Logan, T.; Ryan, J. In Situ Lead Immobilization by Apatite. American Chemical Society. 1993, 27, 1803-1810.

Objectives:
The objective of this paper is to prove the hypothesis that HA dissolution and HP precipitation is the main Pb immobilization process as described to study the feasibility of using apatite to immobilize lead from aqueous solution Pb, resin-exchangeable Pb, and Pb-contaminated soil materials.

Test Methods/Procedures:
Mechanisms of Pb immobilization by HA: 500 mg of aqueous Pb was reacted with .2g of HA. A constant pH was maintained for 1 hour.

Immobilization of aqueous lead by HA and $CaHPO_{4-}$: Pb immobilization by HA was tested by reacting DCP, HA, or a mixture of DCP + HA with aqueous lead. .1-gram calcium phosphate was reacted with 200 mL of 100 and 500 mg Pb/L on a reciprocating shaker for 2 hours.

Immobilization of Pb from Aqueous Solutions, Exchange Resin, and Pb-Contaminated Soil Material by Apatite: HA was reacted with mixtures of different concentrations of aqueous lead. The contaminated soil was mixed with DI water and centrifuged. The filtrates were than analyzed for Pb.

All samples were analyzed using XRD.

Results:
Mechanisms of Pb immobilization by HA: Hydroxypyromorphite was formed in the presence of HA at all pH values tested. At a pH of 3, little HA was detected, indicating that most of the HA had dissolved. The HA peaks became stronger with increasing pH, with the strongest peak at a pH of 5.

Immobilization of aqueous lead by HA and $CaHPO_{4-}$: Sharp, narrow XRD patterns for HP revealed a high degree of crystallinity subsequent to reacting with HA. The HP peaks became stronger and those of HA weaker at the 500 mg of Pb/L level compared to those at the 100 mg level. Similar XRD patterns were obtained from the DCP samples, indicating that the final product (HP) was not dependent upon the structure of the original calcium phosphate.

Immobilization of Pb from Aqueous Solutions, Exchange Resin, and Pb-Contaminated Soil Material by Apatite: In all cases, pH values increased after .5 hour. And the highest pH values were measured in the samples with the lowest initial Pb. Increases in solution pH were caused by HA dissolution. This would not occur if cation substitution was the main mechanism for Pb immobilization. Dissolved Ca concentrations and P increased with an increase in reaction time. Hydroxyapatite was effective in attenuating Pb in aqueous solution, from resin-exchange sites, and dissolved Pb from contaminated soil material. The immobilization process was rapid, rear completion in 30 minutes. Natural apatite was also shown to effectively remove Pb from aqueous solution. Aqueous P is the key factor in determining the effectiveness of lead immobilization by apatite. Thus, pH also plays a role since it determines apatite solubility. Optimal removal of aqueous Pb is achieved when the solution pH is low enough to dissolve apatite and supply P to react with Pb, yet high enough to keep the solubility of HP low.

Article #10

Malinovsky, D.; Rodushkin, I.; Moiseenko, T.; Ohlander, B. Aqueous transport and fate of pollutants in mining area: a case study of Khibiny apatite-nepheline mines, the Kola Peninsula, Russia. Environmental Geology. 2002, 43, 172-187.

Objectives:
The objectives of this study are to characterize features of formation and transport of pollutant fluxes from the mines into surface water; give an assessment of major physico-chemical mechanisms governing the attenuation and fate of pollutants in the water; and work out recommendations for better planning of remediation actions.

Test Methods/Procedures:
Collection of water and sediment samples was undertaken bi-monthly over a 2-year period. Conductivity, pH, alkalinity, dissolved oxygen, and dissolved organic carbon were determined. Dissolved species were divided using an ion exchanger. Deposited sediments were collected, and snow was collected and allowed to melt before testing.

Results:
Anthropogenic fluxes of elements are the main factors controlling water chemistry in the vicinity of the apatite-nepheline mine workings. The most significant changes in water chemistry arise from discharges from the wastewater treatment ponds. Atmospheric transport of the metals from the open-pit mine workings results in metal accumulation in the snow cover of the area during the winter period, and subsequent massive input into the surface water during spring snowmelt. A dilution process from seeps and tributaries mainly accounts for the distinct decreases in the concentrations of Na, K, Ca, Sr, Alk, Sulfate, and Phosphate. Streams draining the Khibiny mine workings have a low capacity to immobilize the pollutants.

Article #11

Manecki, M.; Maurice, P.; Traina, S. Kinetic of aqueous Pb reaction with apatites. Soil Science. 2000, 165, 920-933.

Objectives:
The objectives of this study is to build on past research that supports the idea that phosphate released by the dissolution of apatite reacts with aqueous lead to form highly insoluble Pb phosphates. The resulting Pb-phosphates are pyromorphite, as well as fluor-, and hydroxy-. This study will include Cl and F to represent real world scenarios.

Test Methods/Procedures:
Synthetic hydroxyapatite, natural chlorapatite, and natural fluorapatite were crushed into sand-sized particles, and XRD was performed. Batch experiments were done to compare the dissolved ion concentration patterns resulting from apatite dissolution in the presence and absence of Pbaq. HYDRAQL was used to calculate and plot distributions of phosphate species vs. pH.

Results:
Under batch conditions, and in the presence of Cl ion, the dissolution of apatites is linear. Observed pH increases during apatite dissolution probably resulted from consumption of H+ necessitated by dissolved phosphate equlibria. As pH increases, dissolution rate decreases. In the presence of Pbaq and Cl, all 3 apatites react to form PY. Apatite dissolution rates are enhanced by the presence of Pbaq. The rate-controlling step is apatite dissolution, shown by the dissolved phosphate concentrations during the reaction with Pb(aq).

Article #12

Wright, J.: Conca, J. Remediation of Groundwater Contaminated with Zn, Pb, and Cd using a Permeable Reactive Barrier with Apatite II. RTDF PRB Meeting. 2002, 1-4.

Objectives:
The objectives of this study was to show that apatite II can be used as an in-situ reactive barrier to remove heavy metal contamination.

Test Methods/Procedures:
Ion Chromatography, ICP, Emission and Mass Spectroscopy, Liquid Scintillation Counting, Transmission Electron Microscopy, and Potentiometric Stripping were performed. Batch tests and flow-through column tests were used to determine relative performance and to provide media for solid characterization.

Results:
When Pb was reacted with the apatite, it precipitated as lead-pyromorphites while Zn and Cd both sorbed onto particles and precipitated as hopeite, zincite, hydrocerrusite, otavite and other phases.

3.0 FISH BONE DIGESTS

Fishbone samples from Tank 2, Tank 3, and Tank 4 were digested and analyzed to determine the concentrations of contaminants contained on the fish bone using. Five samples from each tank (one sample at each depth) were dried in an oven for 24 hours at a temperature of 95° Fahrenheit. Digestion of the fish bone followed EPA Test Method 3050B, method two, preparation of sediments, sludges, and soil samples for the analysis of samples by inductively coupled plasma mass spectrometry.

Digested fish bone samples from each tank were sent to SVL Analytical in Kellogg, Idaho for the analysis of Zinc (Zn), Cadmium (Cd), Lead (Pb), Iron (Fe), Manganese (Mn), Magnesium (Mg), and Calcium (Ca), using inductively coupled plasma atomic emission spectrometry (ICP-AES). Samples were prepared according to EPA methods 200.7 and 6010B, and analyzed with a Perkin-Elmer Optima, 2000 DVICP-OES. Table 3-1 represents the results of the digest.

The data obtained from the digest analysis indicate an increase in the concentrations of several metals compared to fish bone that was not exposed to the contaminated water. Samples Raw 1, Raw 2, and Raw 3 were obtained from MSE-TA, Inc. from three different buckets that were collected during installation of the Apatite Treatment System. Comparing these samples to the fish bone samples collected from each treatment tank, the concentration of zinc increased by an average of 97 times; Manganese by 48 times; iron by 18 times; lead by 12 times; and cadmium by 4 times. Magnesium is the only element analyzed for that decreased in concentration.

Table 3-1. Fish Bone Digest Data (mg/kg)

Sample	Ca	Cd	Fe	Mg	Mn	Pb	Zn
Tank 2 Sample 1 surface	214092.14	1.19	3224.93	2755.19	591.69	4.61	14092.14
Tank 2 Sample 2 8"	172946.86	0.89	3449.28	2657.00	656.04	8.07	14685.99
Tank 2 Sample 3 16"	230627.31	0.90	1909.59	2555.35	512.92	2.97	15221.40
Tank 2 Sample 4 24"	205466.54	0.77	1913.29	2516.49	455.23	2.32	12912.35
Tank 2 Sample 5 32"	174077.58	0.66	2204.35	2194.89	586.57	5.09	13907.28
Tank 3 Sample 1 surface	205544.93	1.76	5248.57	2275.33	1414.91	7.02	18355.64
Tank 3 Sample 2 8"	217092.34	2.33	8831.04	2593.32	1886.05	21.51	18565.82
Tamk 3 Sample 3 16"	229166.67	0.99	3001.89	2481.06	945.08	3.89	13825.76
Tank 3 Sample 4 24"	230919.77	1.14	2808.22	2397.26	788.65	4.01	17416.83
Tank 3 Sample 5 32"	219378.43	1.28	3647.17	2550.27	877.51	13.89	18007.31
Tank 4 Sample 1 surface	219178.08	0.85	3268.10	2612.52	675.15	10.08	13698.63
Tank 4 Sample 2 8"	221476.51	0.64	2013.42	2617.45	530.20	3.12	11505.27
Tank 4 Sample 3 16"	178399.23	0.32	1764.71	2314.37	411.76	1.62	7396.34
Tank 4 Sample 4 24"	209960.94	0.53	2861.33	2587.89	723.63	2.71	14062.50
Tank 4 Sample 5 32"	224121.56	0.35	1329.53	2640.08	383.67	0.53	7996.20
Raw 1-Bucket 1	201107.01	0.23	219.56	3173.43	17.25	0.46	167.90
Raw 2-Bucket 2	197926.48	0.23	119.70	3213.95	15.74	0.47	120.64
Raw 3-Bucket 3	212765.96	0.25	168.28	3114.12	14.22	0.48	148.94
Blank	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Duplicate-Tank 2 Sample 3	212389.38	0.88	3008.85	2409.05	489.68	3.47	13372.66

4.0 X-RAY DIFFRACTION (XRD)

Samples from Tank 2, Tank 3, Tank 4, and a sample of the uncontaminated (raw) fishbone were analyzed using XRD to identify any crystalline structures present in the treatment media. Each sample was ground into a fine powder and passed through a 200-mesh (74 micron) screen. The powder was placed in a glass slide, and put into the XRD machine. The beam was set at a start angle of 15° and an end angle of 85°. Readings were taken every one second, or at a scanning step of 0.05° 2θ. Data were then imported into a program called Jade, where it was transformed into a word document. The final data is in a graph representing the d-spacing between the crystalline lattice structures within the sample.

The analysis confirms the composition of the bone as poorly crystalline hydroxyapatite. The samples analyzed from tanks 2, 3, and 4 had no detectable crystalline structures other than that of the hydroxyapatite itself. If any crystalline materials are being produced in the reactor, the mass of the crystalline structure must be too small to detect, or the materials are amorphous and could not be detected using XRD. Figure 4-1 is a representation of the graphs produced by from the XRD analysis. The graphs from all samples were virtually identical.

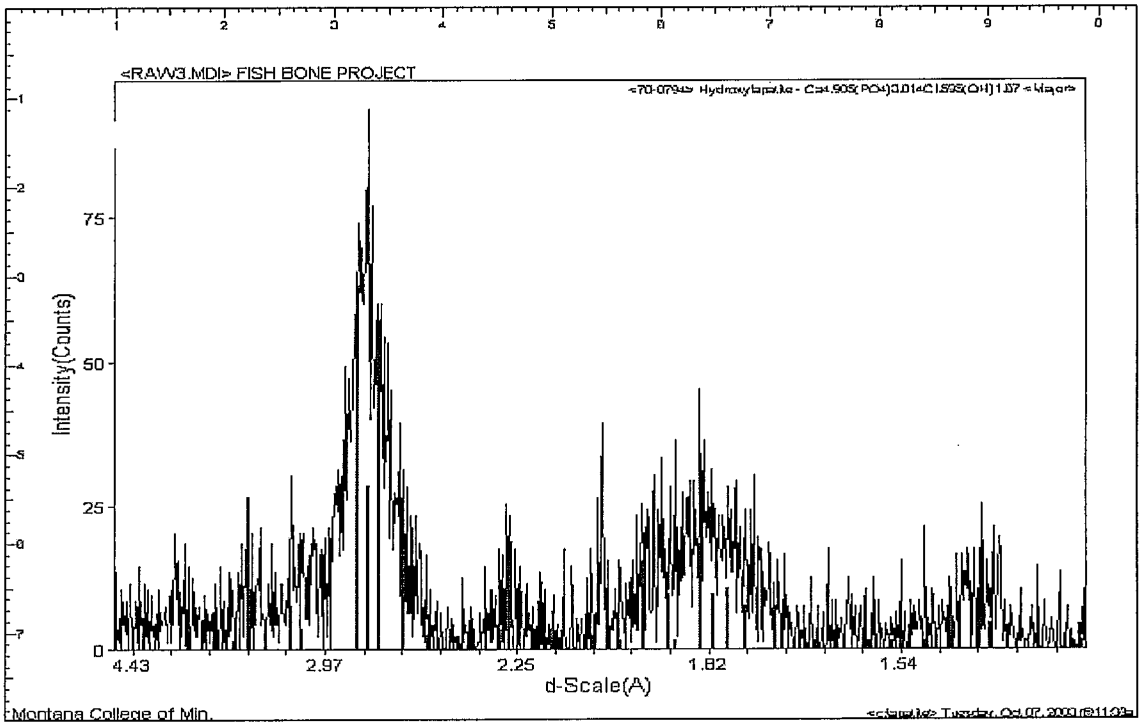

Figure 4-1. XRD Graph

5.0 SCANNING ELECTRON MICROSCOPY/ENERGY DISPERSIVE X-RAYS

Analysis using scanning electron microscopy/energy dispersive X-rays (SEM/EDX) was performed on the raw fishbone as well as the contaminated fishbone from each treatment tank. Analyses were performed at Montana Tech, Butte Montana, and Image and Chemical Analysis Laboratory (ICAL), Bozeman, Montana.

The Scanning Electron Microscope (SEM) has become one of the most widely utilized instruments for material characterization. The SEM is a microscope that uses electrons rather than light to form an image. The SEM has a large depth of field, which allows a large amount of the sample to be in focus at one time. The SEM also produces images of high resolution, which means that closely spaced features can be examined at a high magnification.

A beam of electrons is generated in the electron gun located at the top of a column. This beam is attracted through the anode, condensed by a condenser lens and focused as a very fine point on the sample by the objective lens. The electron beam hits the sample, producing secondary electrons from the sample. These electrons are collected by a secondary detector or a backscatter detector, converted to a voltage, and amplified. The amplified voltage is applied to the grid of the cathode ray tube (CRT) and causes the intensity of the spot of light to change. The image consists of thousands of spots of varying intensity on the face of a CRT that correspond to the topography of the sample.

Fishbone samples from the ATS were placed on a pin stub using double-sided carbon tape. The pin-stubs were placed on an aluminum specimen holder and placed inside the SEM. The system was operated with the variable pressure mode, and an operating chamber pressure of 50 Pascals. 20 kilovolts of accelerating voltage was used for EDX detection. Two fishbone samples were coated with gold to enable high vacuum images to be taken without the interruption of charging. A backscatter detector was used to show variations in the atomic number of contaminants on the fishbone. The following sections discuss samples taken from each treatment tank in detail.

5.1 Un-reacted Fish Bones

A sample of uncontaminated fishbone was analyzed using SEM/EDX. Results from the EDX analysis identify the primary composition of the raw fishbone as oxygen, carbon, calcium, and phosphorus. These results agree with the findings from the XRD that identify the bone as hydroxyapatite. The results are shown in Figure 5-1.

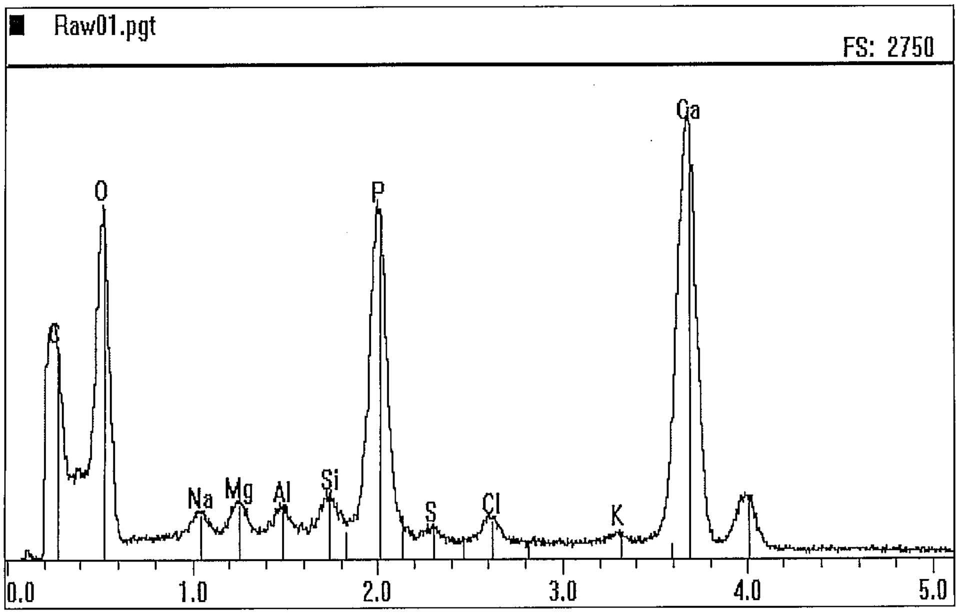

Figure 5-1. Un-reacted Fish Bone EDX Scan.

5.2 Treatment Tank 2

The results from several of the bone samples in treatment tank 2 have similar trends to each other. Zinc was focused on during this project due to the concentrations found in the influent water and on the reacted fish bones. Zinc accounts for approximately six percent of the total sample mass within the scanned area. The EDX analysis also shows a weight percent increase in sulfur. This trend was common in all samples analyzed. The remaining mass can be attributed to calcium, aluminum, phosphorus, silica, and several other metals. Figure 5-2 is a spectrum of the scan area on the bone from treatment tank 2.

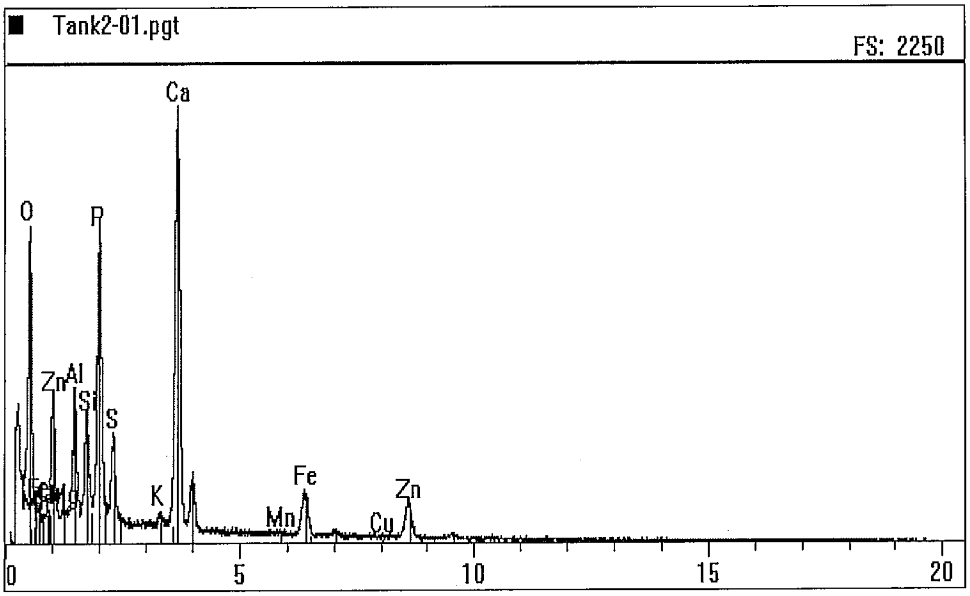

Figure 5-2. Typical EDX Scan for Tank 2

Using the backscatter option on the SEM, a fishbone sample from tank 2 was analyzed. Using the backscatter detector, areas of high average atomic mass show up as bright spots on the bone's surface. Several of these bright spots were scanned and compared with the overall scans of the bones taken from Tank 2. The results from the EDX analysis show that the scan of the selected spot is made up primarily of oxygen, zinc, and sulfur. The zinc is accounting for approximately 18% of the total weight within the scan area, while sulfur accounts for roughly 10%. Figure 5-3 is the EDX scan of a bright spot from Tank 2.

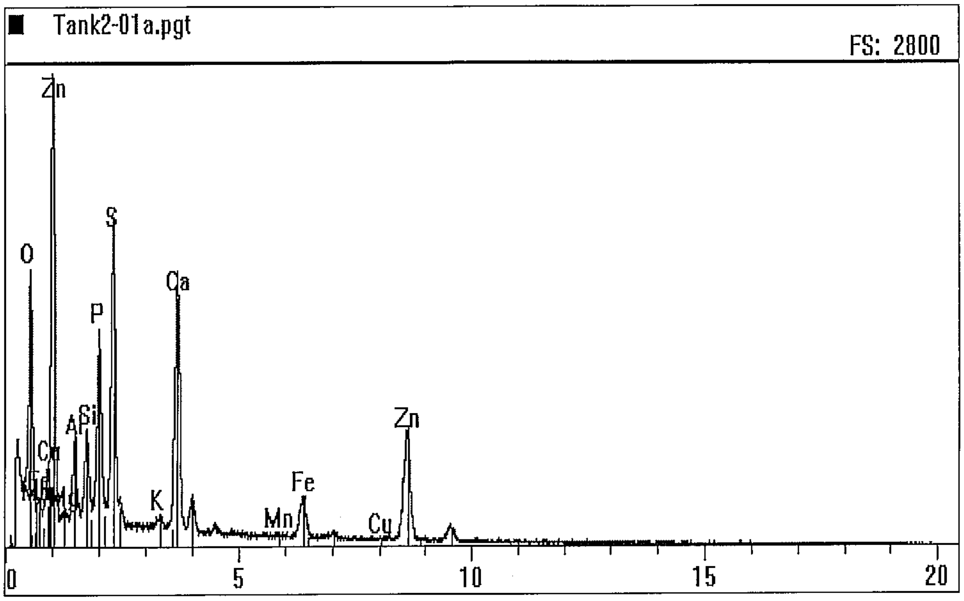

Figure 5-3. EDX Scan of Bright Spot from Tank 2.

5.3 Treatment Tank 3

The bone samples analyzed from treatment tank 3 demonstrate similar results to those from treatment tank 2. Zinc is attributing roughly six percent of the total weight within the scan area, while sulfur contributes about three percent. An additional fishbone sample from Tank 3 was analyzed using the backscatter detector. The EDX analysis of a bright spot shows that zinc is accountable for approximately 16% of the total weight, similar to the 18% found in Tank 2. Similar to results seen in treatment tank 2, the weight percent of sulfur increases. Scans and data from Tank 2 can be found in the appendix of this report.

5.4 Treatment Tank 4

SEM/EDX results indicate that treatment tank 4 has a greater removal efficiency of zinc and other metals when compared to the other treatment tanks. Treatment tanks 2 and 3 have an average zinc weight percent on the surface of the bone of approximately 6. Treatment tank 4 has an average zinc weight percent on the bone surface of roughly 17%. This average is based on the scan covering the entire surface of the fishbone.

Several bone samples from tank 4 were analyzed. Results from all the samples show higher total weight percent of zinc than tanks 2 and 3. Sulfur also contributes a significant amount of the total weight percent. Figure 5.4 is a spectrum of the entire surface of a fishbone sample from tank 4. Table 5.1 is the EDX analysis for this spectrum.

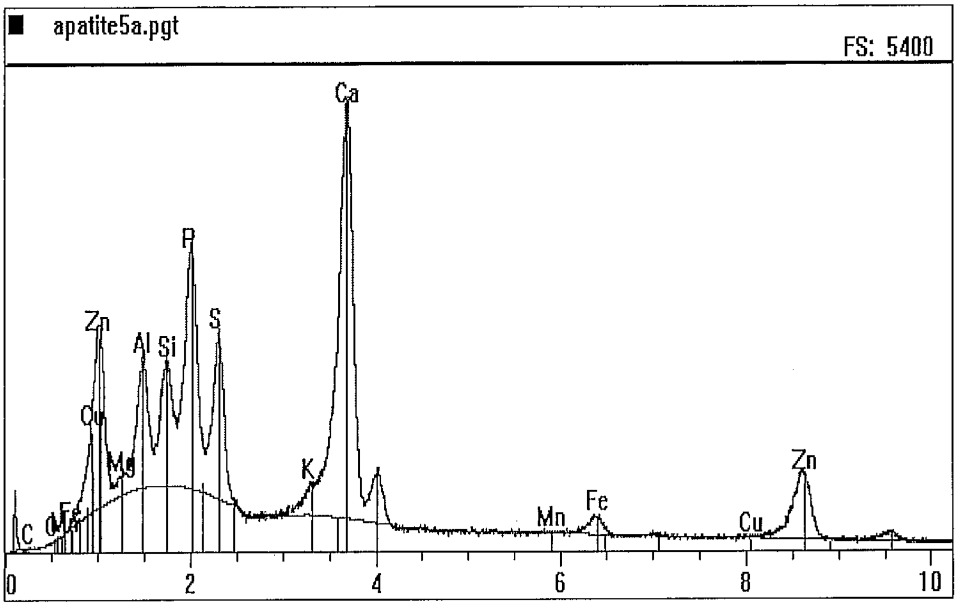

Figure 5.4. EDX Scan of Entire Bone from Tank 4.

Table 5-1. Weight percent Data from EDX Scan

Element	Wt%	At%
Zn	16.90	9.40
Fe	2.10	1.36
Ca	26.41	23.98
P	22.51	26.44
Si	6.44	8.34
Al	7.67	10.35
O	0.00	0.00
S	12.75	14.46
Mg	1.75	2.62
Cu	0.37	0.21
K	2.90	2.70
C	0.00	0.00
Mn	0.21	0.14
Total	**100.00**	**100.00**

The backscatter detector was also used to look at a sample of fishbone from treatment tank 4. Due to the high levels of zinc present on the bone samples from treatment tank 4, and the use of the SEM backscatter detector, more light intensified spots could be found. This enabled the comparison of the bright spots to the darker gray regions of the fishbone. Figure 5-5 is an image showing two scan areas. When compared to the total weight percent of zinc that treatment tanks 2 and 3 are removing, treatment Tank 4 four appears to be more efficient in removing zinc and other metals.

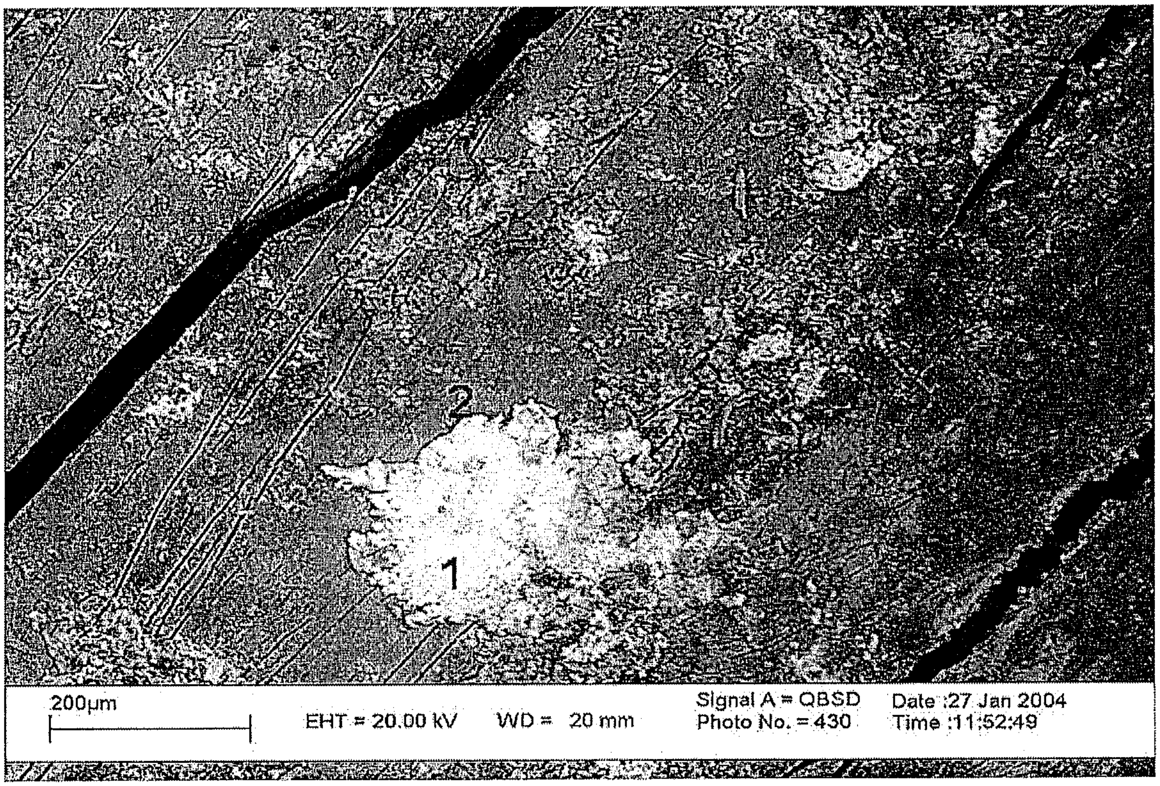

Figure 5-5. Bright Regions (1) and Dark Regions (2)

The following tables represent the weight percent of various elements found within the bright and dark regions.

Table 5-2. Weight Percent Data from Bright Region

Element	Wt%	At%
O	25.68	49.16
Mg	0.21	0.26
Al	4.42	5.02
Si	0.88	0.96
P	3.78	3.73
S	17.38	16.60
K	0.00	0.00
Ca	6.06	4.63
Mn	0.34	0.19
Fe	0.80	0.44
Cu	3.93	1.90
Zn	36.52	17.11
Total	**100.00**	**100.00**

Table 5-3. Weight Percent Data from Dark Region

Element	Wt%	At%
O	62.31	79.65
Mg	0.00	0.00
Al	2.53	1.92
Si	0.54	0.39
P	7.84	5.18
S	4.79	3.05
K	0.00	0.00
Ca	14.55	7.42
Mn	0.20	0.07
Fe	0.67	0.25
Cu	0.63	0.20
Zn	5.96	1.87
Total	**100.00**	**100.00**

Results from Table 5-2 show that the bright spot that was analyzed is 36.5 percent zinc and 17.4 percent sulfur. These two elements account for more than half of the total weight percent in the area that was scanned. Results from Table 5-3 show that the dark region that was scanned is approximately six percent zinc, while sulfur is roughly five percent of the total weight. Results from all of the SEM/EDX analyses suggest that the zinc and sulfur are directly related, thus suggesting the formation of zinc sulfide. More tests and experiments focusing on this aspect can be found in Devin Clary's thesis, which was defended in April 2004.

To confirm the presence of zinc sulfide, a fishbone sample taken from tank four was analyzed under high vacuum using the SEM. Figure 5-6 is an image of zinc sulfide crystals that were formed on the surface of a fishbone sample from tank four. This image is magnified 9000 times and has a scale of 300 nanometers.

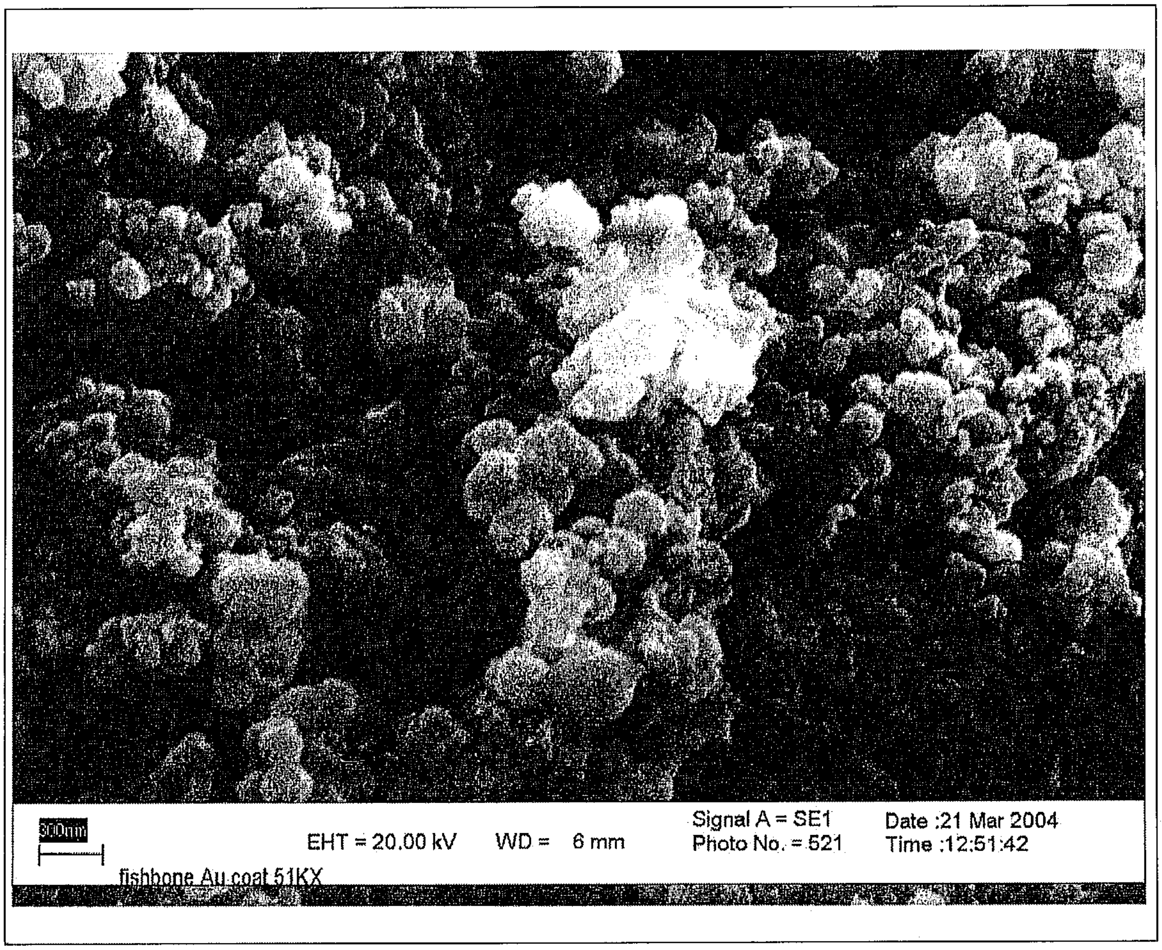

Figure 5-6. Zinc Sulfide Crystals

The spherical structures within the image were identified as zinc sulfide crystals. Research performed by Gammons and Frandsen (2001) identified similar shaped zinc sulfide crystals in an anaerobic treatment system. Table 5-4 is an EDX analysis of Figure 5-6. The zinc accounts for over thirty six percent of the total weight within that scan region, while sulfur contributes over seventeen percent of the total weight.

Table 5-4. EDX Analysis of ZnS Crystals.

Element	Wt%	At%
O	25.68	49.16
Mg	0.21	0.26
Al	4.42	5.02
Si	0.88	0.96
P	3.78	3.73
S	17.38	16.60
K	0.00	0.00
Ca	6.06	4.63
Mn	0.34	0.19
Fe	0.80	0.44
Cu	3.93	1.90
Zn	36.52	17.11
Total	**100.00**	**100.00**

Since zinc sulfide is being precipitated in the ATS, it can be stated that Cd, Fe, and Pb are also being precipitated as metal sulfides. This is due to the solubility products of each metal. ZnS is the most soluble, which indicates that CdS and PbS should precipitate before ZnS. Table 5-5 is a list of the solubility products of cadmium, lead, and zinc.

Table 5-5. Solubility Products

Metal Sulfide	Formation	Log K
CdS (Greenockite)	$CdS + H^+ \leftrightarrow Cd^{2+} + HS^-$	-15.93
PbS (Galena)	$PbS + H^+ \leftrightarrow Pb^{2+} + HS^-$	-12.78
ZnS (Sphalerite)	$ZnS + H^+ \leftrightarrow Zn^{2+} + HS^-$	-11.62

Source: Drever 1997

6.0 CONCLUSIONS

The apatite treatment system placed at the Nevada-Stewart Mine is removing metals. Results of the digests show increases in metals concentrations compared to the un-reacted fish bones. The metals most common in the influent water show the greatest increases. The XRD tests were somewhat inconclusive other than verifying the composition of the fish bones as hydroxyapatite.

Tests conducted on the SEM/EDX provided the most compelling evidence of metal removal. Numerous highly conductive spots were found on the bone samples collected from each of the three treatment tanks. The samples collected from Tank 4, however, had more conductive areas than the other two tanks. These "spots" were analyzed and compared to other areas of the bone to determine how the metals were being removed. Zinc was focused on because it has the highest concentrations and it was easier to find on the bone samples.

Results from the SEM/EDX analyses and the results from additional tests outlined in Clary's thesis suggest that zinc is being removed from the Nevada-Stewart Mine water through the precipitation of a zinc sulfide. This contradicts current literature that suggests zinc is removed with apatite through the precipitation of a zinc phosphate. No evidence was found to support the precipitation of zinc phosphate in the treatment system at the Nevada-Stewart mine site. The following is a summary of the probable zinc removal mechanisms taking place within the ATS:

- Precipitation of zinc sulfide assisted by sulfate reducing bacteria—primary removal mechanism,
- Precipitation of a zinc phosphate or zinc oxide, and
- Isomorphous substitution.

Additional experiments are needed to better understand the sulfate reducing bacteria that are responsible for the metal attenuation. Identification of the bacteria would better promote the recent finding of zinc sulfide precipitation assisted by SRB formation in the Nevada-Stewart Mine apatite treatment system.

Metal removal using fishbone apatite could also be optimized. Since it was determined that SRB activity was responsible for the attenuation of zinc and possibly other metals at the Nevada-Stewart Mine through the precipitation of a metal sulfides, the system could be designed to be an anoxic, highly reduced environment: the favored conditions of SRB. A flow rate control would be required to ensure the contaminated water receive the proper residence time within the treatment tanks.

7.0 REFERENCES

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Appendix I – SEM Data

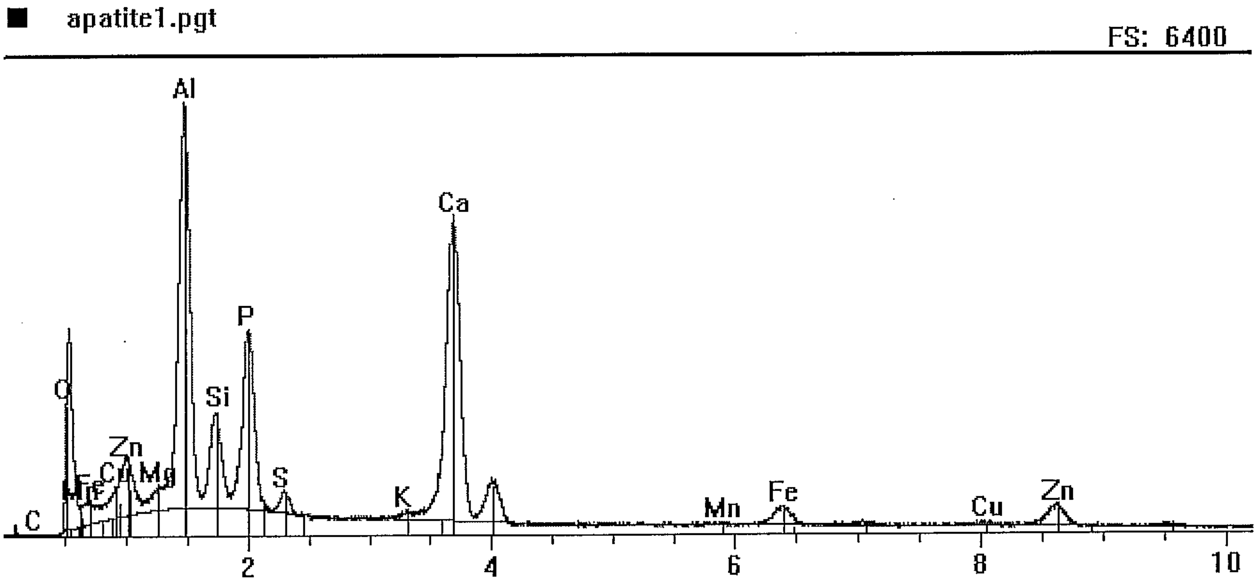
PGT
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 2 Spot on ground-up sample

File:	C:\Program Files\PGT\Data\apatite1.pgt
Collected:	October 27, 2003 12:29:20

Live Time:	339.16	Count Rate:	2265	Dead Time:	16.28 %
Beam Voltage:	14.78	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0910	10.98	4.22	1.75
Fe	KA1	6.403	0.0270	3.09	1.39	1.32
Ca	KA1	3.691	0.1622	17.60	11.03	8.41
P	KA1	2.013	0.0588	8.31	6.74	56.06
Si	KA1	1.740	0.0287	4.34	3.88	56.06
Al	KA1	1.487	0.1145	17.75	16.52	56.06
O	KA1	0.523	0.0829	33.98	53.32	56.06
S	KA1	2.307	0.0063	0.83	0.65	56.06
Mg	KA1	1.254	0.0079	1.43	1.48	56.06
Cu	KA1	8.046	0.0090	1.07	0.42	1.75
K	KA1	3.313	0.0042	0.45	0.29	8.41
C	KA1	0.277	0.0000	0.00	0.00	0.00
Mn	KA1	5.898	0.0013	0.16	0.07	1.32
Total				**100.00**	**100.00**	**32.46**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	34.7	10.6	0.0	24.0	2.3
Fe	KA1	32.4	12.3	0.1	20.0	1.6
Ca	KA1	297.4	18.0	0.4	279.0	15.5
P	KA1	171.8	28.2	0.0	143.7	5.1
Si	KA1	104.2	30.0	0.1	74.1	2.5
Al	KA1	329.4	28.5	0.0	300.9	10.6
O	KA1	89.4	4.9	1.8	82.7	17.0
S	KA1	39.9	25.2	0.2	14.5	0.6
Mg	KA1	45.9	25.0	0.1	20.8	0.8
Cu	KA1	14.6	11.3	0.0	3.3	0.3
K	KA1	26.5	18.9	0.0	7.6	0.4
C	KA1	0.5	0.6	0.0	0.0	0.0
Mn	KA1	13.7	12.5	0.0	1.2	0.1

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.993	1.197	1.008	1.000	1.207	Elmnt.
Fe	KA1	0.984	1.137	1.027	0.977	1.142	Elmnt.
Ca	KA1	0.936	1.014	1.075	0.996	1.086	Elmnt.
P	KA1	0.904	0.998	1.426	0.993	1.414	Elmnt.
Si	KA1	0.865	0.959	1.588	0.992	1.511	Elmnt.
Al	KA1	0.861	0.979	1.592	0.994	1.550	Elmnt.
O	KA1	0.168	0.863	4.758	0.999	4.101	Elmnt.
S	KA1	0.887	0.979	1.354	0.990	1.312	Elmnt.
Mg	KA1	0.795	0.943	1.941	0.991	1.815	Elmnt.
Cu	KA1	0.991	1.191	1.012	0.985	1.187	Elmnt.
K	KA1	0.919	1.033	1.107	0.949	1.086	Elmnt.
C	KA1	0.024	0.816	8.425	0.999	6.870	Elmnt.
Mn	KA1	0.980	1.154	1.039	0.983	1.178	Elmnt.

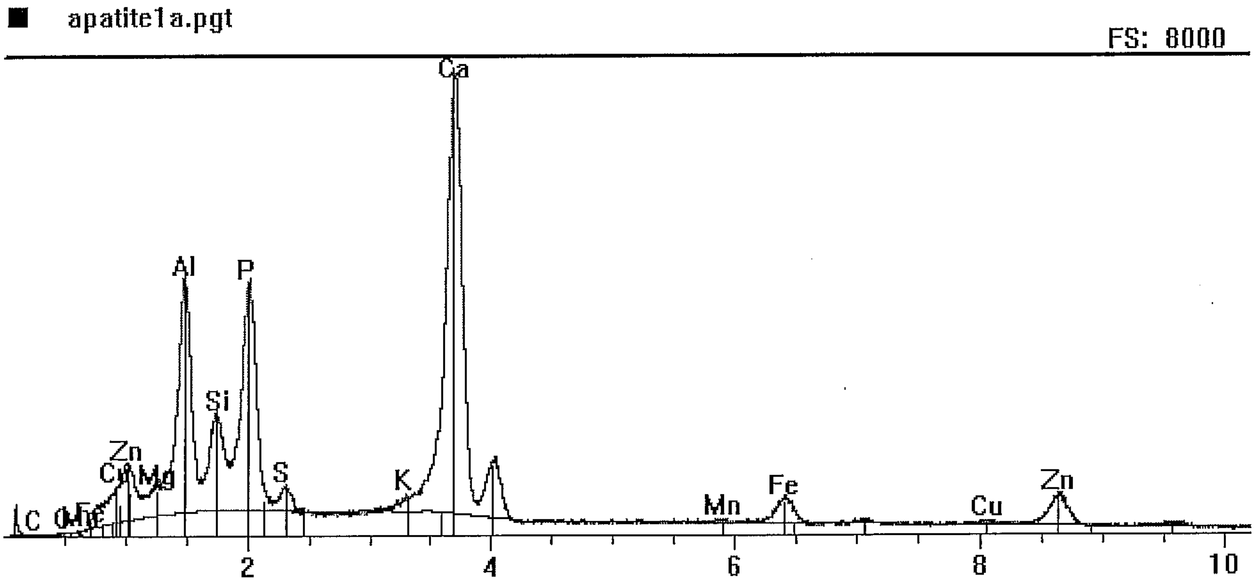
PGT
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 2 Entire bone in ground-up sample

File: C:\Program Files\PGT\Data\apatite1a.pgt
Collected: October 27, 2003 12:29:20

Live Time:	281.13	Count Rate:	4203	Dead Time:	26.30 %
Beam Voltage:	19.40	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0777	9.14	4.87	3.37
Fe	KA1	6.403	0.0315	3.66	2.28	2.35
Ca	KA1	3.691	0.2863	32.52	28.28	110.28
P	KA1	2.013	0.1824	26.42	29.73	47.84
Si	KA1	1.740	0.0391	5.99	7.43	47.84
Al	KA1	1.487	0.0868	14.48	18.72	47.84
O	KA1	0.523	0.0000	0.00	0.00	0.00
S	KA1	2.307	0.0151	2.31	2.51	47.84
Mg	KA1	1.254	0.0152	3.02	4.33	47.84
Cu	KA1	8.046	0.0069	0.81	0.44	3.37
K	KA1	3.313	0.0122	1.38	1.23	110.28
C	KA1	0.277	0.0000	0.00	0.00	0.00
Mn	KA1	5.898	0.0023	0.28	0.18	2.35
Total				**100.00**	**100.00**	**54.02**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	77.0	21.3	0.0	55.6	2.6
Fe	KA1	67.1	25.3	0.3	41.5	1.6
Ca	KA1	685.6	42.5	1.6	641.5	15.1
P	KA1	340.4	41.7	0.1	298.6	7.2
Si	KA1	172.5	41.0	0.1	131.4	3.2
Al	KA1	319.3	36.4	0.0	282.9	7.8
O	KA1	3.8	4.1	0.0	0.0	0.0
S	KA1	71.0	41.4	0.5	29.2	0.7
Mg	KA1	76.4	30.0	0.1	46.2	1.5
Cu	KA1	28.6	22.7	0.0	5.8	0.3
K	KA1	70.2	43.3	0.0	26.8	0.6
C	KA1	1.2	1.6	0.0	0.0	0.0
Mn	KA1	29.3	26.0	0.0	3.3	0.1

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.979	1.149	1.024	1.000	1.176	Elmnt.
Fe	KA1	0.953	1.104	1.069	0.983	1.160	Elmnt.
Ca	KA1	0.806	0.993	1.147	0.997	1.136	Elmnt.
P	KA1	0.436	0.984	1.489	0.989	1.449	Elmnt.
Si	KA1	0.813	0.946	1.651	0.981	1.532	Elmnt.
Al	KA1	0.784	0.967	1.749	0.987	1.669	Elmnt.
O	KA1	0.049	0.858	8.969	0.999	7.692	Elmnt.
S	KA1	0.527	0.964	1.607	0.985	1.526	Elmnt.
Mg	KA1	0.689	0.933	2.160	0.989	1.992	Elmnt.
Cu	KA1	0.975	1.147	1.033	0.990	1.173	Elmnt.
K	KA1	0.752	1.013	1.200	0.933	1.134	Elmnt.
C	KA1	0.003	0.816	13.444	1.000	10.961	Elmnt.
Mn	KA1	0.941	1.123	1.095	0.986	1.212	Elmnt.

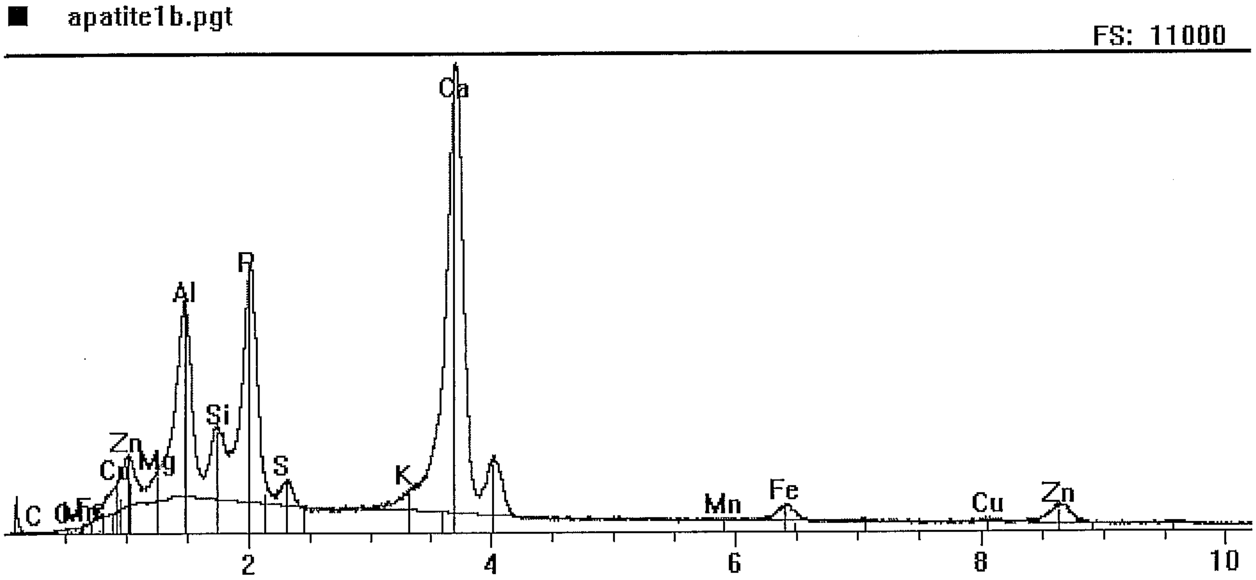
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 2 entire ground-up sample

File:	C:\Program Files\PGT\Data\apatite1b.pgt
Collected:	October 27, 2003 12:29:20

Live Time:	302.00	Count Rate:	5498	Dead Time:	30.79 %
Beam Voltage:	19.48	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0306	3.63	1.78	3.81
Fe	KA1	6.403	0.0125	1.47	0.85	2.35
Ca	KA1	3.691	0.2319	27.71	22.21	284.17
P	KA1	2.013	0.3417	43.75	45.37	83.82
Si	KA1	1.740	0.0222	2.90	3.32	83.82
Al	KA1	1.487	0.0598	8.58	10.22	83.82
O	KA1	0.523	0.0052	4.11	8.25	83.82
S	KA1	2.307	0.0209	3.52	3.53	83.82
Mg	KA1	1.254	0.0128	2.13	2.82	83.82
Cu	KA1	8.046	0.0032	0.39	0.20	3.81
K	KA1	3.313	0.0137	1.68	1.38	284.17
C	KA1	0.277	0.0000	0.00	0.00	0.00
Mn	KA1	5.898	0.0009	0.12	0.07	2.35
Total				**100.00**	**100.00**	**125.72**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	68.4	24.9	0.0	43.5	1.7
Fe	KA1	62.7	30.8	0.2	31.7	1.0
Ca	KA1	895.2	48.8	2.7	843.6	17.3
P	KA1	457.9	65.4	0.1	392.4	6.0
Si	KA1	202.7	71.7	0.1	131.0	1.8
Al	KA1	392.5	74.6	0.0	317.9	4.3
O	KA1	6.4	6.3	0.0	0.1	0.0
S	KA1	99.4	60.4	0.6	38.3	0.6
Mg	KA1	118.9	62.3	0.2	56.4	0.9
Cu	KA1	32.2	26.8	0.0	5.4	0.2
K	KA1	98.1	52.4	0.0	45.7	0.9
C	KA1	1.9	2.1	0.0	0.0	0.0
Mn	KA1	34.4	31.8	0.0	2.6	0.1

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.970	1.164	1.020	1.000	1.187	Elmnt.
Fe	KA1	0.931	1.117	1.067	0.993	1.184	Elmnt.
Ca	KA1	0.722	1.005	1.191	0.999	1.195	Elmnt.
P	KA1	0.255	0.995	1.299	0.991	1.280	Elmnt.
Si	KA1	0.759	0.956	1.423	0.962	1.309	Elmnt.
Al	KA1	0.705	0.978	1.503	0.976	1.435	Elmnt.
O	KA1	0.008	0.868	9.076	0.999	7.871	Elmnt.
S	KA1	0.360	0.975	1.745	0.989	1.682	Elmnt.
Mg	KA1	0.582	0.943	1.795	0.983	1.665	Elmnt.
Cu	KA1	0.963	1.162	1.028	0.996	1.190	Elmnt.
K	KA1	0.649	1.025	1.257	0.952	1.226	Elmnt.
C	KA1	0.000	0.825	18.554	1.000	15.299	Elmnt.
Mn	KA1	0.914	1.136	1.092	0.994	1.234	Elmnt.

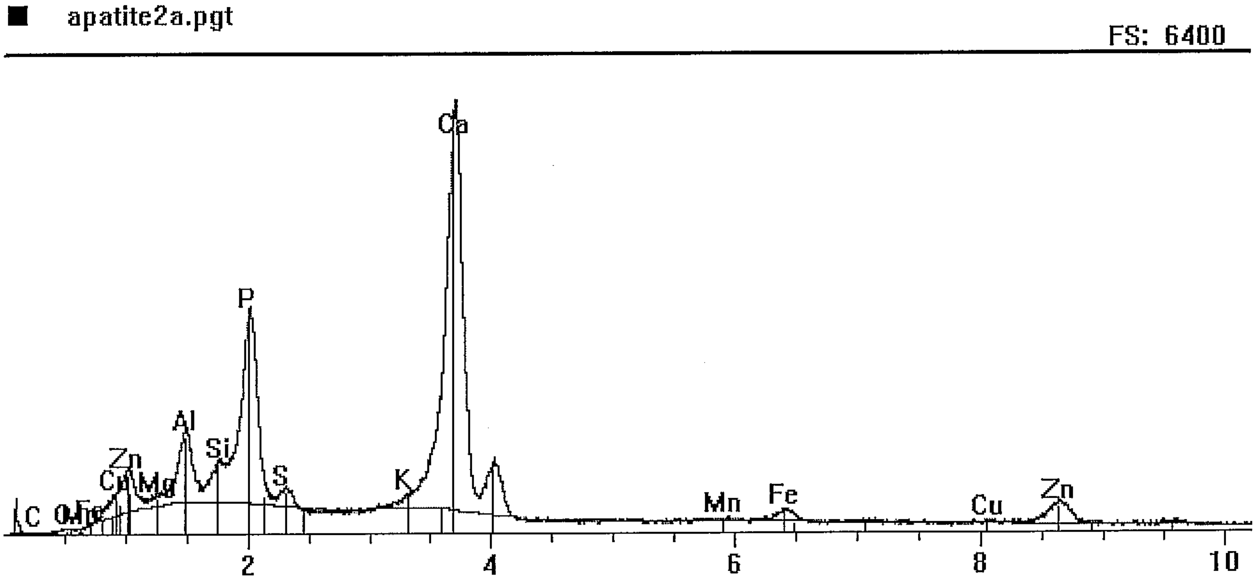
PGT
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 3 Piece of bone in ground-up sample

File:	C:\Program Files\PGT\Data\apatite2a.pgt
Collected:	October 27, 2003 12:29:20

Live Time:	223.74	Count Rate:	3719	Dead Time:	25.10 %
Beam Voltage:	19.34	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0596	7.03	3.80	3.45
Fe	KA1	6.403	0.0154	1.81	1.14	1.68
Ca	KA1	3.691	0.3170	36.75	32.40	170.84
P	KA1	2.013	0.3160	39.98	45.61	36.59
Si	KA1	1.740	0.0191	2.50	3.15	36.59
Al	KA1	1.487	0.0326	5.02	6.58	36.59
O	KA1	0.523	0.0000	0.00	0.00	0.00
S	KA1	2.307	0.0190	2.99	3.30	36.59
Mg	KA1	1.254	0.0071	1.31	1.91	36.59
Cu	KA1	8.046	0.0037	0.43	0.24	3.45
K	KA1	3.313	0.0156	1.81	1.64	170.84
C	KA1	0.277	0.0000	0.00	0.00	0.00
Mn	KA1	5.898	0.0029	0.36	0.23	1.68
Total				**100.00**	**100.00**	**73.05**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	59.7	19.4	0.0	40.4	2.1
Fe	KA1	42.6	23.4	0.3	18.9	0.8
Ca	KA1	645.8	45.3	1.6	598.8	13.2
P	KA1	311.7	49.8	0.0	261.8	5.3
Si	KA1	108.8	52.0	0.0	56.8	1.1
Al	KA1	139.5	49.6	0.0	89.9	1.8
O	KA1	5.6	6.4	0.0	0.0	0.0
S	KA1	69.0	46.3	0.4	22.3	0.5
Mg	KA1	58.2	41.1	0.1	17.0	0.4
Cu	KA1	23.3	20.3	0.0	2.9	0.1
K	KA1	72.8	45.1	0.0	27.7	0.6
C	KA1	1.8	2.0	0.0	0.0	0.0
Mn	KA1	28.0	24.1	0.0	3.9	0.2

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.975	1.154	1.024	1.000	1.181	Elmnt.
Fe	KA1	0.942	1.108	1.075	0.988	1.177	Elmnt.
Ca	KA1	0.761	0.997	1.166	0.998	1.159	Elmnt.
P	KA1	0.330	0.987	1.297	0.989	1.265	Elmnt.
Si	KA1	0.784	0.949	1.435	0.965	1.314	Elmnt.
Al	KA1	0.742	0.970	1.623	0.979	1.542	Elmnt.
O	KA1	0.020	0.861	9.736	0.999	8.374	Elmnt.
S	KA1	0.432	0.967	1.653	0.985	1.574	Elmnt.
Mg	KA1	0.631	0.935	2.009	0.987	1.855	Elmnt.
Cu	KA1	0.969	1.152	1.033	0.993	1.181	Elmnt.
K	KA1	0.696	1.016	1.221	0.936	1.161	Elmnt.
C	KA1	0.000	0.818	14.833	1.000	12.127	Elmnt.
Mn	KA1	0.927	1.126	1.102	0.991	1.230	Elmnt.

PGT
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

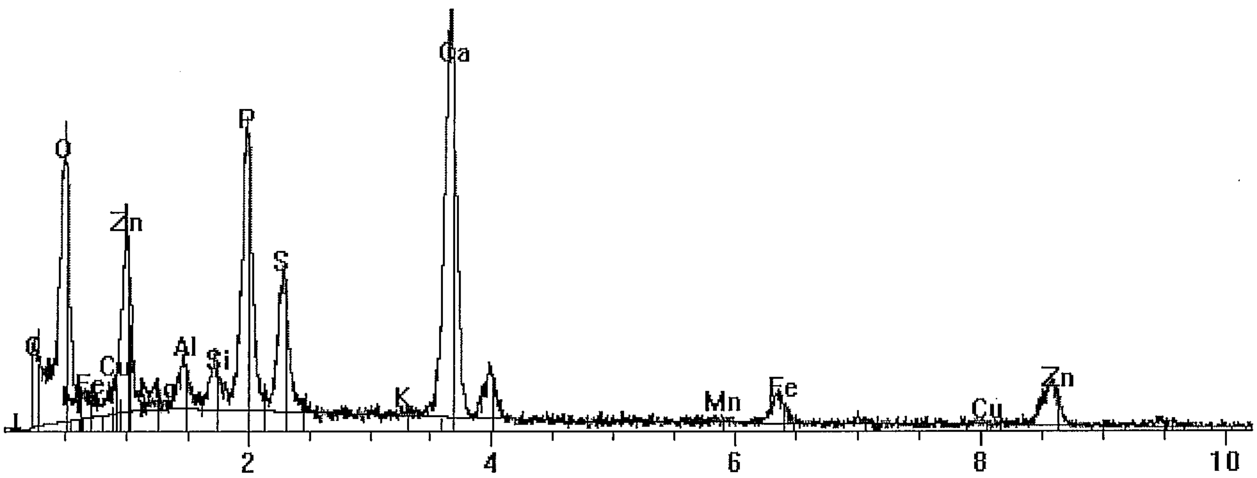
Tank 3 Spot on piece of bone

File:	C:\Program Files\PGT\Data\apatite2bspotonlargepc.pgt
Collected:	October 28, 2003 13:18:21

Live Time:	500.65	Count Rate:	167	Dead Time:	6.63 %
Beam Voltage:	18.64	Beam Current:	2.00	Takeoff Angle:	31.00

■ apatite2bspotonlargepc.pgt

FS: 640



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0053	0.72	0.16	5.18
Fe	KA1	6.403	0.0016	0.20	0.05	2.25
Ca	KA1	3.691	0.0116	1.35	0.48	22.78
P	KA1	2.013	0.0100	1.29	0.59	12.06
Si	KA1	1.740	0.0009	0.12	0.06	12.06
Al	KA1	1.487	0.0009	0.14	0.07	12.06
O	KA1	0.523	0.0581	47.00	41.39	12.06
S	KA1	2.307	0.0044	0.55	0.24	12.06
Mg	KA1	1.254	0.0002	0.04	0.02	12.06
Cu	KA1	8.046	0.0001	0.01	0.00	5.18
K	KA1	3.313	0.0004	0.04	0.01	22.78
C	KA1	0.277	0.1705	48.52	56.92	12.06
Mn	KA1	5.898	0.0001	0.01	0.00	2.25
Total				**100.00**	**100.00**	**11.91**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	3.6	0.6	0.0	3.0	4.9
Fe	KA1	2.4	0.8	0.0	1.6	2.2
Ca	KA1	22.7	1.2	0.0	21.4	17.8
P	KA1	15.1	1.6	0.0	13.5	8.7
Si	KA1	4.1	1.6	0.0	2.5	1.5
Al	KA1	3.9	1.6	0.0	2.3	1.4
O	KA1	12.2	0.6	0.0	11.7	20.3
S	KA1	8.5	1.5	0.0	7.0	4.7
Mg	KA1	2.0	1.5	0.0	0.5	0.3
Cu	KA1	0.7	0.7	0.0	0.1	0.1
K	KA1	1.9	1.3	0.0	0.6	0.5
C	KA1	3.8	0.3	1.5	2.1	8.0
Mn	KA1	0.9	0.8	0.0	0.1	0.1

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.987	1.378	0.989	1.000	1.363	Elmnt.
Fe	KA1	0.971	1.314	0.988	0.985	1.278	Elmnt.
Ca	KA1	0.881	1.176	0.992	0.998	1.165	Elmnt.
P	KA1	0.674	1.164	1.122	0.995	1.299	Elmnt.
Si	KA1	0.860	1.119	1.229	0.993	1.366	Elmnt.
Al	KA1	0.855	1.144	1.426	0.996	1.624	Elmnt.
O	KA1	0.201	1.016	7.970	1.000	8.096	Elmnt.
S	KA1	0.719	1.140	1.098	0.995	1.246	Elmnt.
Mg	KA1	0.790	1.103	1.778	0.998	1.957	Elmnt.
Cu	KA1	0.984	1.373	0.989	0.990	1.343	Elmnt.
K	KA1	0.847	1.199	1.004	0.976	1.176	Elmnt.
C	KA1	0.044	0.966	2.948	1.000	2.845	Elmnt.
Mn	KA1	0.964	1.335	0.990	0.989	1.306	Elmnt.

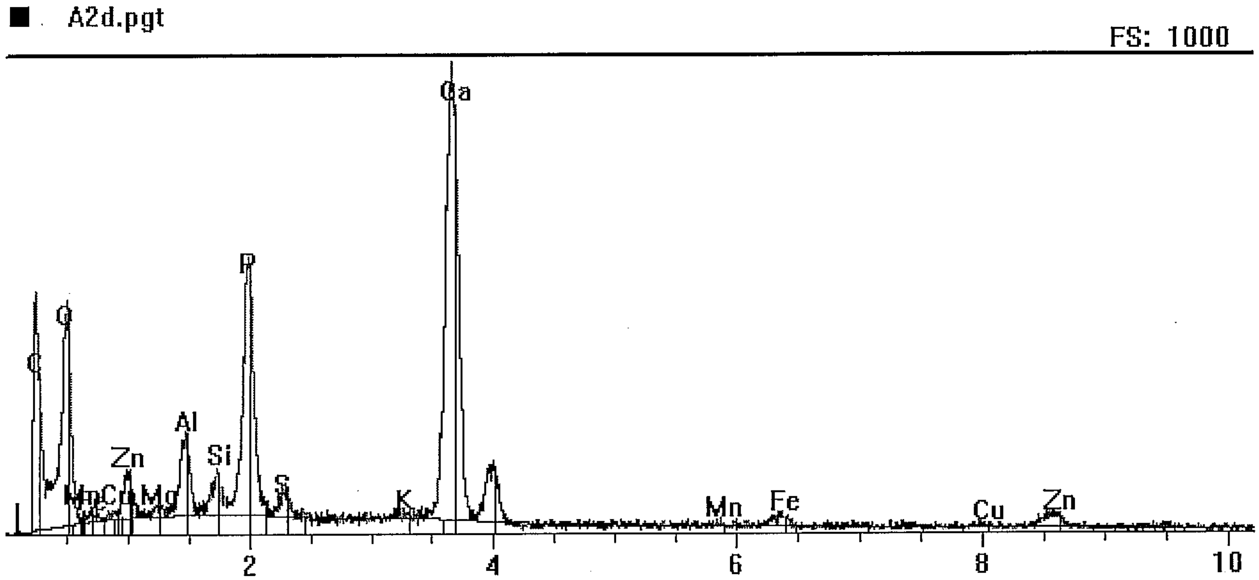
PGT
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 3 Bone scan

File: C:\Program Files\PGT\Data\vern\A2d.pgt
Collected: October 28, 2003 13:18:21

Live Time:	1293.82	Count Rate:	85	Dead Time:	6.32 %
Beam Voltage:	18.54	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
C	KA1	0.277	0.2475	58.39	67.04	23.85
O	KA1	0.523	0.0354	35.62	30.70	23.85
Al	KA1	1.487	0.0024	0.38	0.19	23.85
S	KA1	2.307	0.0011	0.14	0.06	23.85
K	KA1	3.313	0.0008	0.09	0.03	47.49
Ca	KA1	3.691	0.0239	2.77	0.95	47.49
Fe	KA1	6.403	0.0013	0.17	0.04	1.40
Zn	KA1	8.637	0.0035	0.48	0.10	2.36
P	KA1	2.013	0.0132	1.68	0.75	23.85
Si	KA1	1.740	0.0013	0.17	0.08	23.85
Mg	KA1	1.254	0.0003	0.06	0.03	23.85
Cu	KA1	8.046	0.0004	0.05	0.01	2.36
Mn	KA1	5.898	0.0001	0.02	0.00	1.40
Total				**100.00**	**100.00**	**25.68**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
C	KA1	4.9	0.1	0.0	4.7	32.2
O	KA1	5.6	0.3	0.0	5.2	16.3
Al	KA1	3.1	0.8	0.0	2.3	2.9
S	KA1	1.5	0.8	0.0	0.7	0.9
K	KA1	1.2	0.7	0.0	0.5	0.7
Ca	KA1	15.9	0.7	0.0	15.2	22.2
Fe	KA1	0.8	0.4	0.0	0.4	1.2
Zn	KA1	0.9	0.3	0.0	0.6	2.2
P	KA1	8.4	0.8	0.0	7.5	9.2
Si	KA1	2.0	0.8	0.0	1.2	1.4
Mg	KA1	1.0	0.7	0.0	0.3	0.4
Cu	KA1	0.4	0.3	0.0	0.1	0.3
Mn	KA1	0.5	0.4	0.0	0.1	0.1

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
C	KA1	0.052	0.970	2.433	1.000	2.359	Elmnt.
O	KA1	0.220	1.021	9.848	1.000	10.048	Elmnt.
Al	KA1	0.860	1.149	1.351	0.996	1.546	Elmnt.
S	KA1	0.733	1.145	1.083	0.992	1.230	Elmnt.
K	KA1	0.854	1.205	0.992	0.959	1.145	Elmnt.
Ca	KA1	0.886	1.182	0.984	0.999	1.161	Elmnt.
Fe	KA1	0.972	1.320	0.991	0.992	1.298	Elmnt.
Zn	KA1	0.988	1.385	0.990	1.000	1.371	Elmnt.
P	KA1	0.693	1.169	1.096	0.995	1.274	Elmnt.
Si	KA1	0.863	1.124	1.189	0.992	1.326	Elmnt.
Mg	KA1	0.797	1.108	1.655	0.997	1.830	Elmnt.
Cu	KA1	0.985	1.379	0.990	0.995	1.359	Elmnt.
Mn	KA1	0.965	1.341	0.993	0.994	1.324	Elmnt.

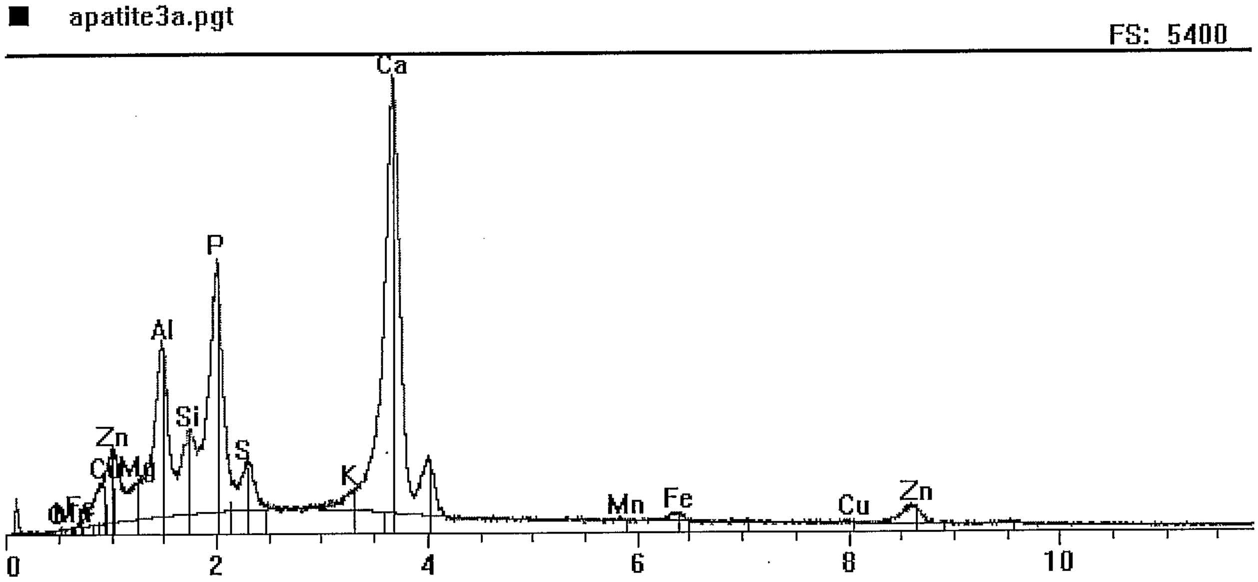
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 4 Entire ground-up sample

File: C:\Program Files\PGT\Data\vern\apatite3a.pgt
Collected: October 29, 2003 12:12:50

Live Time:	133.92	Count Rate:	5989	Dead Time:	32.39 %
Beam Voltage:	19.46	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Al	KA1	1.487	0.0788	12.66	16.10	45.05
Si	KA1	1.740	0.0445	6.55	8.00	45.05
S	KA1	2.307	0.0323	4.78	5.11	45.05
K	KA1	3.313	0.0258	2.91	2.56	78.98
Ca	KA1	3.691	0.3209	36.98	31.64	78.98
Fe	KA1	6.403	0.0122	1.45	0.89	1.26
P	KA1	2.013	0.1669	23.64	26.17	45.05
Zn	KA1	8.637	0.0530	6.28	3.30	3.22
Cu	KA1	8.046	0.0037	0.44	0.24	3.22
Mn	KA1	5.898	0.0007	0.08	0.05	1.26
Mg	KA1	1.254	0.0227	4.22	5.96	45.05
O	KA1	0.523	0.0000	0.00	0.00	0.00
Total				**100.00**	**100.00**	**45.08**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Al	KA1	373.8	42.2	0.2	331.4	7.8
Si	KA1	236.7	48.4	0.3	188.0	3.9
S	KA1	160.2	60.6	1.3	98.3	1.6
K	KA1	139.1	63.4	0.0	75.7	1.2
Ca	KA1	991.2	57.2	4.6	929.4	16.2
Fe	KA1	53.5	33.8	0.1	19.5	0.6
P	KA1	538.8	55.7	0.3	482.8	8.7
Zn	KA1	71.7	25.9	0.0	45.8	1.8
Cu	KA1	32.2	28.5	0.0	3.8	0.1
Mn	KA1	38.1	36.9	0.0	1.2	0.0
Mg	KA1	128.5	34.4	0.9	93.1	2.7
O	KA1	8.1	9.2	0.0	0.0	0.0

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Al	KA1	0.832	0.974	1.672	0.986	1.606	Elmnt.
Si	KA1	0.845	0.953	1.579	0.979	1.474	Elmnt.
S	KA1	0.651	0.971	1.552	0.982	1.481	Elmnt.
K	KA1	0.815	1.021	1.192	0.928	1.129	Elmnt.
Ca	KA1	0.856	1.001	1.153	0.998	1.152	Elmnt.
Fe	KA1	0.965	1.113	1.077	0.989	1.185	Elmnt.
P	KA1	0.587	0.991	1.449	0.986	1.416	Elmnt.
Zn	KA1	0.985	1.158	1.024	1.000	1.186	Elmnt.
Cu	KA1	0.981	1.157	1.033	0.993	1.187	Elmnt.
Mn	KA1	0.957	1.132	1.105	0.992	1.240	Elmnt.
Mg	KA1	0.756	0.940	2.007	0.988	1.864	Elmnt.
O	KA1	0.128	0.865	10.010	0.999	8.652	Elmnt.

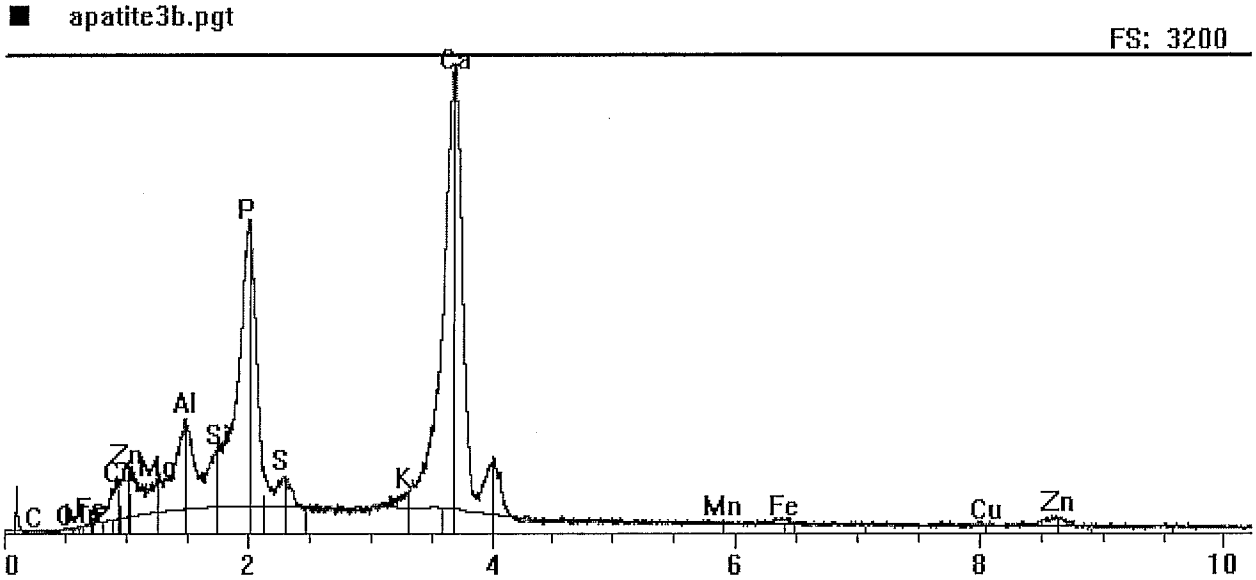
PGT
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 4 Spot on bone in ground-up sample

File:	C:\Program Files\PGT\Data\vern\apatite3b.pgt
Collected:	October 29, 2003 12:12:50

Live Time:	60.91	Count Rate:	7567	Dead Time:	37.24 %
Beam Voltage:	19.15	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0132	1.57	0.80	1.17
Fe	KA1	6.403	0.0036	0.43	0.26	0.85
Ca	KA1	3.691	0.2314	28.18	23.35	44.28
P	KA1	2.013	0.4612	54.56	58.48	28.95
Si	KA1	1.740	0.0206	2.41	2.85	28.95
Al	KA1	1.487	0.0289	3.85	4.74	28.95
O	KA1	0.523	0.0000	0.00	0.00	0.00
S	KA1	2.307	0.0259	4.45	4.60	28.95
Mg	KA1	1.254	0.0145	2.19	2.99	28.95
Cu	KA1	8.046	0.0016	0.19	0.10	1.17
K	KA1	3.313	0.0169	2.13	1.81	44.28
C	KA1	0.277	0.0000	0.00	0.00	0.00
Mn	KA1	5.898	0.0003	0.03	0.02	0.85
Total				**100.00**	**100.00**	**27.82**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	59.5	31.5	0.0	28.0	0.9
Fe	KA1	52.7	38.6	0.1	14.0	0.4
Ca	KA1	1363.6	90.3	5.6	1267.7	14.0
P	KA1	844.8	91.6	0.3	752.9	8.2
Si	KA1	272.2	86.1	0.3	185.9	2.2
Al	KA1	311.3	78.7	0.2	232.4	3.0
O	KA1	11.2	13.2	0.0	0.0	0.0
S	KA1	161.4	90.1	2.4	68.9	0.8
Mg	KA1	162.2	65.4	0.9	95.8	1.5
Cu	KA1	37.6	33.6	0.0	4.0	0.1
K	KA1	176.2	92.0	0.0	84.2	0.9
C	KA1	3.6	8.2	0.0	0.0	0.0
Mn	KA1	43.3	42.2	0.0	1.2	0.0

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.961	1.171	1.018	1.000	1.192	Elmnt.
Fe	KA1	0.911	1.122	1.066	0.997	1.193	Elmnt.
Ca	KA1	0.650	1.008	1.208	1.000	1.218	Elmnt.
P	KA1	0.153	0.998	1.197	0.991	1.183	Elmnt.
Si	KA1	0.710	0.959	1.287	0.947	1.169	Elmnt.
Al	KA1	0.636	0.981	1.406	0.968	1.335	Elmnt.
O	KA1	0.002	0.870	9.072	0.999	7.888	Elmnt.
S	KA1	0.250	0.978	1.773	0.990	1.716	Elmnt.
Mg	KA1	0.495	0.946	1.629	0.981	1.511	Elmnt.
Cu	KA1	0.953	1.168	1.026	0.998	1.196	Elmnt.
K	KA1	0.564	1.028	1.277	0.959	1.260	Elmnt.
C	KA1	0.000	0.827	20.669	1.000	17.082	Elmnt.
Mn	KA1	0.889	1.141	1.090	0.998	1.241	Elmnt.

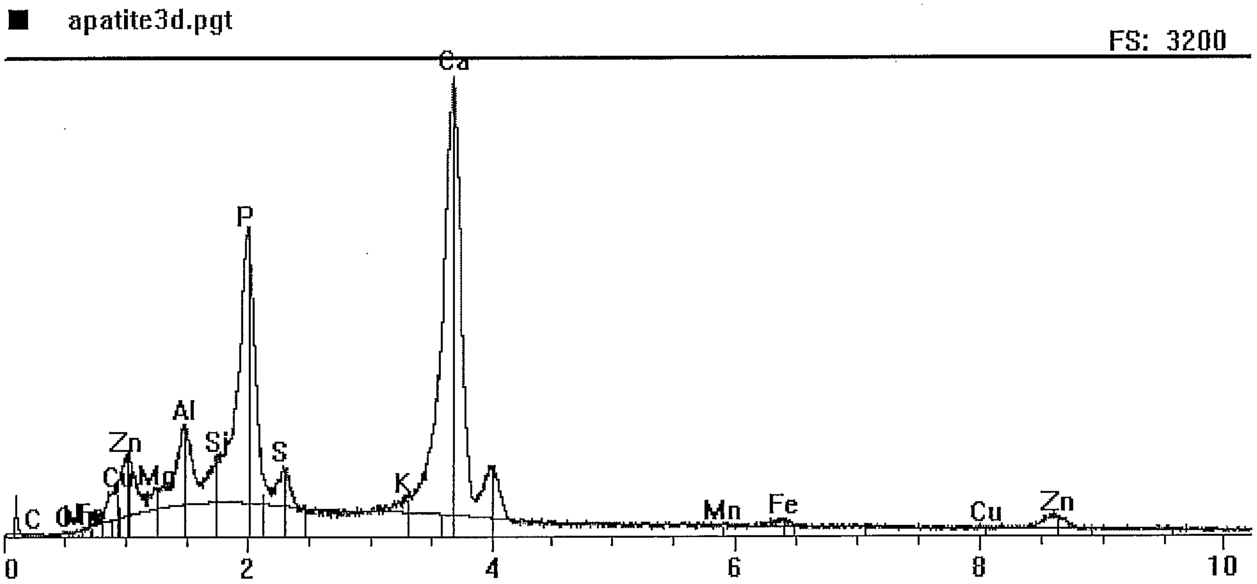
PGT
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 4 Scan of crack in bone

File:	C:\Program Files\PGT\Data\vern\apatite3d.pgt
Collected:	October 29, 2003 12:12:50

Live Time:	65.37	Count Rate:	6893	Dead Time:	35.12 %
Beam Voltage:	19.57	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0405	4.81	2.57	1.60
Fe	KA1	6.403	0.0096	1.15	0.72	1.13
Ca	KA1	3.691	0.3522	40.90	35.61	43.89
P	KA1	2.013	0.2671	34.22	38.55	18.87
Si	KA1	1.740	0.0266	3.52	4.38	18.87
Al	KA1	1.487	0.0392	6.00	7.76	18.87
O	KA1	0.523	0.0000	0.00	0.00	0.00
S	KA1	2.307	0.0282	4.30	4.68	18.87
Mg	KA1	1.254	0.0127	2.30	3.29	18.87
Cu	KA1	8.046	0.0012	0.14	0.08	1.60
K	KA1	3.313	0.0233	2.65	2.37	43.89
C	KA1	0.277	0.0000	0.00	0.00	0.00
Mn	KA1	5.898	0.0001	0.01	0.01	1.13
Total				**100.00**	**100.00**	**23.33**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	71.3	28.7	0.0	42.5	1.5
Fe	KA1	55.0	36.6	0.0	18.4	0.5
Ca	KA1	1229.9	73.0	4.6	1152.2	15.8
P	KA1	763.2	105.5	0.2	657.5	6.2
Si	KA1	234.3	103.7	0.2	130.4	1.3
Al	KA1	283.4	97.0	0.1	186.3	1.9
O	KA1	9.5	10.2	0.0	0.0	0.0
S	KA1	178.3	95.6	1.8	80.9	0.8
Mg	KA1	137.9	80.6	0.8	56.6	0.7
Cu	KA1	32.4	31.0	0.0	1.4	0.0
K	KA1	154.2	79.1	0.0	75.1	0.9
C	KA1	3.5	6.4	0.0	0.0	0.0
Mn	KA1	40.1	39.9	0.0	0.2	0.0

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.982	1.158	1.025	1.000	1.188	Elmnt.
Fe	KA1	0.960	1.113	1.083	0.992	1.195	Elmnt.
Ca	KA1	0.834	1.001	1.161	0.999	1.161	Elmnt.
P	KA1	0.517	0.992	1.311	0.986	1.282	Elmnt.
Si	KA1	0.831	0.953	1.434	0.968	1.324	Elmnt.
Al	KA1	0.811	0.975	1.601	0.980	1.530	Elmnt.
O	KA1	0.085	0.865	10.653	0.999	9.213	Elmnt.
S	KA1	0.595	0.971	1.598	0.982	1.525	Elmnt.
Mg	KA1	0.727	0.940	1.950	0.987	1.810	Elmnt.
Cu	KA1	0.979	1.157	1.035	0.995	1.191	Elmnt.
K	KA1	0.788	1.021	1.206	0.927	1.142	Elmnt.
C	KA1	0.008	0.822	13.789	1.000	11.335	Elmnt.
Mn	KA1	0.950	1.132	1.112	0.994	1.251	Elmnt.

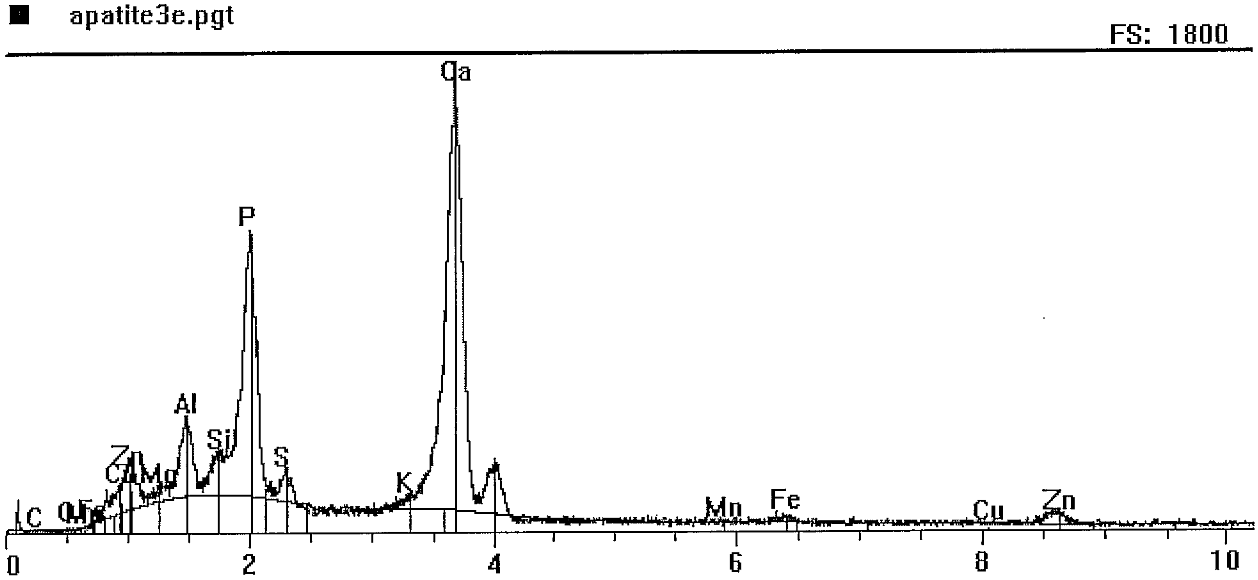
PGT
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 4 Scan of piece of bone

File:	C:\Program Files\PGT\Data\vern\apatite3e.pgt
Collected:	October 29, 2003 12:12:50

Live Time:	37.02	Count Rate:	6240	Dead Time:	33.00 %
Beam Voltage:	18.88	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0367	4.36	2.33	1.44
Fe	KA1	6.403	0.0090	1.08	0.67	0.98
Ca	KA1	3.691	0.3585	41.35	36.01	20.63
P	KA1	2.013	0.2978	37.08	41.79	8.19
Si	KA1	1.740	0.0235	3.00	3.73	8.19
Al	KA1	1.487	0.0385	5.66	7.32	8.19
O	KA1	0.523	0.0000	0.00	0.00	0.00
S	KA1	2.307	0.0235	3.56	3.88	8.19
Mg	KA1	1.254	0.0088	1.53	2.20	8.19
Cu	KA1	8.046	0.0010	0.12	0.07	1.44
K	KA1	3.313	0.0196	2.22	1.99	20.63
C	KA1	0.277	0.0000	0.00	0.00	0.00
Mn	KA1	5.898	0.0002	0.03	0.02	0.98
Total				**100.00**	**100.00**	**11.00**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	60.3	24.9	0.0	35.4	1.4
Fe	KA1	48.3	31.9	0.0	16.3	0.5
Ca	KA1	1165.3	75.1	3.6	1086.5	14.5
P	KA1	688.0	112.5	0.2	575.4	5.1
Si	KA1	223.7	114.2	0.2	109.3	1.0
Al	KA1	279.2	107.9	0.1	171.2	1.6
O	KA1	7.2	8.4	0.0	0.0	0.0
S	KA1	153.4	95.5	1.6	56.3	0.6
Mg	KA1	126.1	89.5	0.6	35.9	0.4
Cu	KA1	28.7	27.5	0.0	1.2	0.0
K	KA1	136.7	79.0	0.0	57.7	0.7
C	KA1	2.8	6.8	0.0	0.0	0.0
Mn	KA1	35.2	34.7	0.0	0.5	0.0

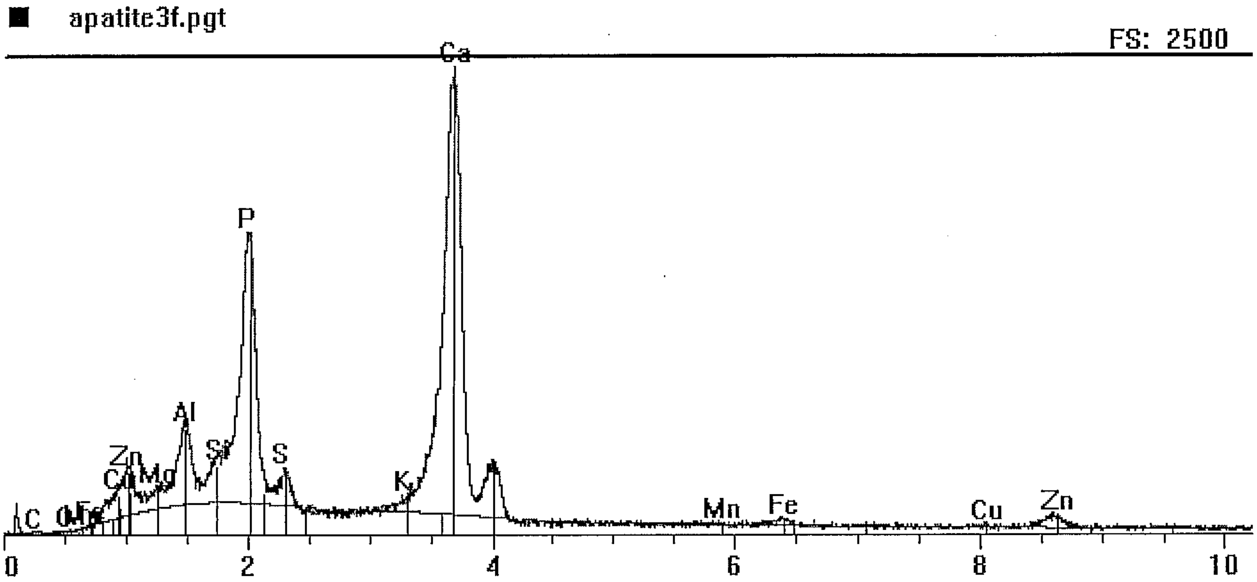
Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.979	1.162	1.023	1.000	1.189	Elmnt.
Fe	KA1	0.952	1.115	1.077	0.993	1.193	Elmnt.
Ca	KA1	0.801	1.002	1.152	0.999	1.153	Elmnt.
P	KA1	0.424	0.991	1.272	0.987	1.245	Elmnt.
Si	KA1	0.810	0.953	1.389	0.966	1.279	Elmnt.
Al	KA1	0.780	0.974	1.541	0.979	1.470	Elmnt.
O	KA1	0.044	0.864	10.123	0.999	8.742	Elmnt.
S	KA1	0.517	0.971	1.586	0.983	1.515	Elmnt.
Mg	KA1	0.683	0.940	1.874	0.987	1.738	Elmnt.
Cu	KA1	0.974	1.160	1.032	0.996	1.192	Elmnt.
K	KA1	0.746	1.022	1.199	0.928	1.137	Elmnt.
C	KA1	0.002	0.821	13.544	1.000	11.111	Elmnt.
Mn	KA1	0.940	1.133	1.104	0.995	1.245	Elmnt.

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 4 Spot on bone chip

File:	C:\Program Files\PGT\Data\vern\apatite3f.pgt
Collected:	October 29, 2003 12:12:50

Live Time:	51.37	Count Rate:	6520	Dead Time:	33.82 %
Beam Voltage:	19.33	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0333	3.96	2.11	1.46
Fe	KA1	6.403	0.0080	0.96	0.60	1.00
Ca	KA1	3.691	0.3493	40.60	35.19	33.61
P	KA1	2.013	0.2868	36.20	40.60	13.65
Si	KA1	1.740	0.0261	3.39	4.19	13.65
Al	KA1	1.487	0.0387	5.77	7.43	13.65
O	KA1	0.523	0.0000	0.00	0.00	0.00
S	KA1	2.307	0.0266	4.07	4.41	13.65
Mg	KA1	1.254	0.0119	2.08	2.98	13.65
Cu	KA1	8.046	0.0025	0.30	0.17	1.46
K	KA1	3.313	0.0223	2.56	2.27	33.61
C	KA1	0.277	0.0000	0.00	0.00	0.00
Mn	KA1	5.898	0.0008	0.11	0.07	1.00
Total				**100.00**	**100.00**	**18.01**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	60.9	24.6	0.0	36.3	1.5
Fe	KA1	49.4	33.2	0.2	16.0	0.5
Ca	KA1	1243.1	68.5	4.5	1170.1	17.1
P	KA1	741.0	98.7	0.2	642.0	6.5
Si	KA1	230.4	97.1	0.2	133.1	1.4
Al	KA1	279.7	90.6	0.1	188.9	2.1
O	KA1	7.6	7.7	0.0	0.0	0.0
S	KA1	163.9	89.7	1.8	72.4	0.8
Mg	KA1	128.9	74.8	0.7	53.4	0.7
Cu	KA1	30.5	27.2	0.0	3.3	0.1
K	KA1	147.7	74.6	0.0	73.0	1.0
C	KA1	2.6	5.6	0.0	0.0	0.0
Mn	KA1	37.5	35.6	0.0	1.8	0.1

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.980	1.161	1.024	1.000	1.189	Elmnt.
Fe	KA1	0.955	1.114	1.080	0.993	1.196	Elmnt.
Ca	KA1	0.813	1.002	1.161	0.999	1.162	Elmnt.
P	KA1	0.455	0.992	1.289	0.987	1.262	Elmnt.
Si	KA1	0.817	0.954	1.406	0.966	1.296	Elmnt.
Al	KA1	0.791	0.975	1.562	0.979	1.492	Elmnt.
O	KA1	0.056	0.866	10.447	0.999	9.037	Elmnt.
S	KA1	0.544	0.972	1.603	0.983	1.532	Elmnt.
Mg	KA1	0.698	0.941	1.893	0.987	1.757	Elmnt.
Cu	KA1	0.976	1.159	1.034	0.996	1.193	Elmnt.
K	KA1	0.761	1.022	1.207	0.929	1.146	Elmnt.
C	KA1	0.004	0.822	14.018	1.000	11.525	Elmnt.
Mn	KA1	0.943	1.133	1.108	0.995	1.250	Elmnt.

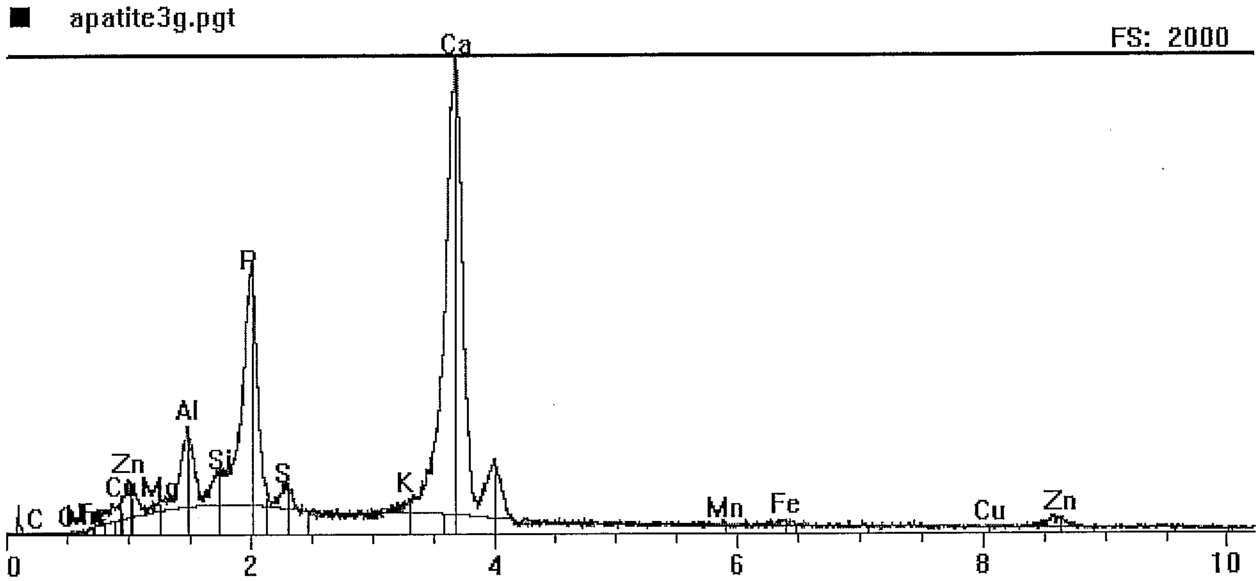
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 4 Spot next to crack

File:	C:\Program Files\PGT\Data\vern\apatite3g.pgt
Collected:	October 29, 2003 12:12:50

Live Time:	41.41	Count Rate:	5600	Dead Time:	30.68 %
Beam Voltage:	18.92	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0295	3.52	1.89	1.16
Fe	KA1	6.403	0.0058	0.70	0.44	1.14
Ca	KA1	3.691	0.4047	46.25	40.53	26.59
P	KA1	2.013	0.2808	34.74	39.39	9.40
Si	KA1	1.740	0.0215	2.74	3.43	9.40
Al	KA1	1.487	0.0390	5.72	7.45	9.40
O	KA1	0.523	0.0000	0.00	0.00	0.00
S	KA1	2.307	0.0187	2.77	3.03	9.40
Mg	KA1	1.254	0.0069	1.19	1.73	9.40
Cu	KA1	8.046	0.0000	0.00	0.00	0.00
K	KA1	3.313	0.0208	2.31	2.07	26.59
C	KA1	0.277	0.0000	0.00	0.00	0.00
Mn	KA1	5.898	0.0005	0.07	0.04	1.14
Total				**100.00**	**100.00**	**14.46**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	48.4	21.6	0.0	26.9	1.2
Fe	KA1	38.9	29.0	0.1	9.9	0.3
Ca	KA1	1231.6	65.2	3.6	1162.7	17.8
P	KA1	626.8	88.2	0.1	538.4	6.1
Si	KA1	181.6	87.2	0.2	94.2	1.1
Al	KA1	245.3	81.0	0.1	164.2	2.0
O	KA1	4.0	4.1	0.0	0.0	0.0
S	KA1	123.5	78.3	1.5	43.8	0.6
Mg	KA1	93.3	66.2	0.5	26.6	0.4
Cu	KA1	24.2	24.0	0.0	0.0	0.0
K	KA1	128.1	69.7	0.0	58.4	0.8
C	KA1	1.8	3.5	0.0	0.0	0.0
Mn	KA1	32.1	31.2	0.0	1.0	0.0

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.979	1.163	1.025	1.000	1.192	Elmnt.
Fe	KA1	0.953	1.115	1.082	0.995	1.201	Elmnt.
Ca	KA1	0.806	1.003	1.141	0.999	1.143	Elmnt.
P	KA1	0.436	0.992	1.265	0.985	1.237	Elmnt.
Si	KA1	0.813	0.954	1.385	0.967	1.277	Elmnt.
Al	KA1	0.784	0.975	1.536	0.980	1.467	Elmnt.
O	KA1	0.049	0.865	10.727	0.999	9.271	Elmnt.
S	KA1	0.527	0.972	1.550	0.981	1.478	Elmnt.
Mg	KA1	0.689	0.940	1.876	0.987	1.741	Elmnt.
Cu	KA1	0.975	1.160	1.034	0.997	1.196	Elmnt.
K	KA1	0.752	1.023	1.183	0.917	1.109	Elmnt.
C	KA1	0.003	0.821	12.248	1.000	10.056	Elmnt.
Mn	KA1	0.941	1.134	1.111	0.996	1.255	Elmnt.

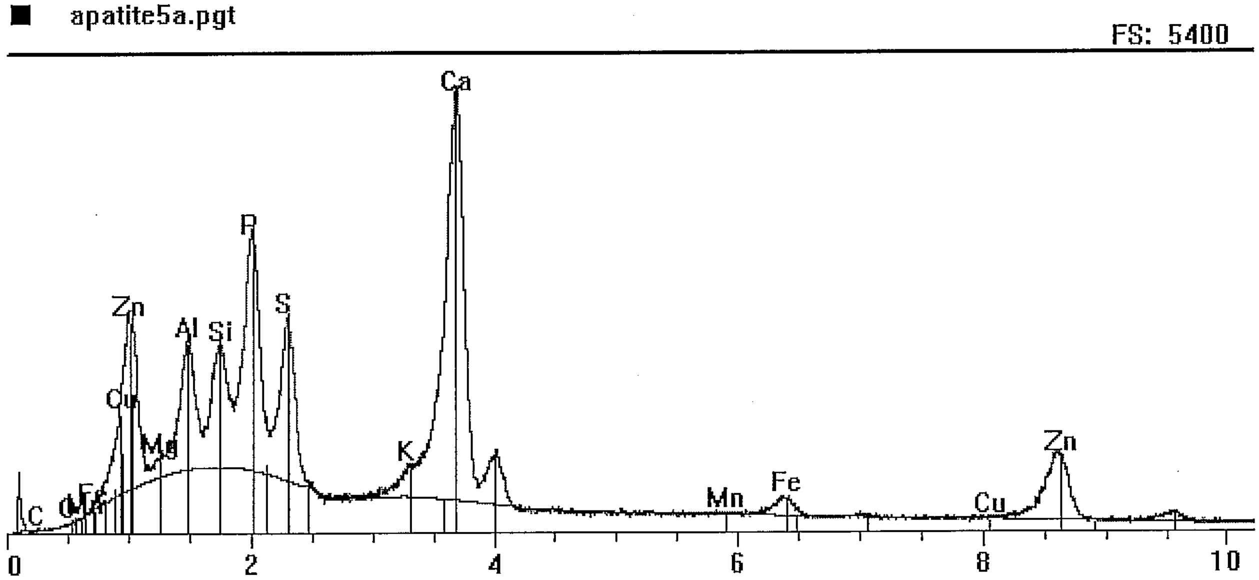
PGT
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 4 Entire piece of long, flakey bone

File: C:\Program Files\PGT\Data\vern\apatite5a.pgt
Collected: October 29, 2003 12:12:50

Live Time:	141.63	Count Rate:	8355	Dead Time:	39.09 %
Beam Voltage:	19.23	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.1454	16.90	9.40	12.68
Fe	KA1	6.403	0.0186	2.10	1.36	1.60
Ca	KA1	3.691	0.2274	26.41	23.98	81.57
P	KA1	2.013	0.1577	22.51	26.44	19.09
Si	KA1	1.740	0.0428	6.44	8.34	19.09
Al	KA1	1.487	0.0431	7.67	10.35	19.09
O	KA1	0.523	0.0000	0.00	0.00	0.00
S	KA1	2.307	0.0867	12.75	14.46	19.09
Mg	KA1	1.254	0.0080	1.75	2.62	19.09
Cu	KA1	8.046	0.0032	0.37	0.21	12.68
K	KA1	3.313	0.0246	2.90	2.70	81.57
C	KA1	0.277	0.0000	0.00	0.00	0.00
Mn	KA1	5.898	0.0017	0.21	0.14	1.60
Total				**100.00**	**100.00**	**31.52**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	211.4	36.8	0.0	174.6	4.7
Fe	KA1	90.0	48.3	0.4	41.3	0.9
Ca	KA1	967.7	86.9	5.7	875.1	10.1
P	KA1	623.5	152.3	0.4	470.8	3.1
Si	KA1	402.9	155.7	0.2	247.0	1.6
Al	KA1	391.6	149.3	0.1	242.2	1.6
O	KA1	20.1	20.0	0.0	0.0	0.0
S	KA1	427.0	127.2	1.2	298.6	2.3
Mg	KA1	170.3	126.7	1.5	42.1	0.3
Cu	KA1	44.9	40.3	0.0	4.6	0.1
K	KA1	186.7	93.1	0.0	93.7	1.0
C	KA1	5.9	6.5	0.0	0.0	0.0
Mn	KA1	56.7	52.4	0.0	4.2	0.1

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.987	1.139	1.020	1.000	1.162	Elmnt.
Fe	KA1	0.970	1.095	1.064	0.970	1.129	Elmnt.
Ca	KA1	0.877	0.986	1.183	0.996	1.162	Elmnt.
P	KA1	0.661	0.976	1.484	0.986	1.427	Elmnt.
Si	KA1	0.857	0.939	1.635	0.980	1.505	Elmnt.
Al	KA1	0.852	0.960	1.878	0.987	1.778	Elmnt.
O	KA1	0.188	0.851	8.294	0.999	7.056	Elmnt.
S	KA1	0.709	0.956	1.557	0.988	1.471	Elmnt.
Mg	KA1	0.785	0.925	2.397	0.991	2.198	Elmnt.
Cu	KA1	0.984	1.137	1.028	0.981	1.147	Elmnt.
K	KA1	0.842	1.005	1.233	0.952	1.180	Elmnt.
C	KA1	0.038	0.809	15.242	1.000	12.326	Elmnt.
Mn	KA1	0.963	1.114	1.088	0.978	1.185	Elmnt.

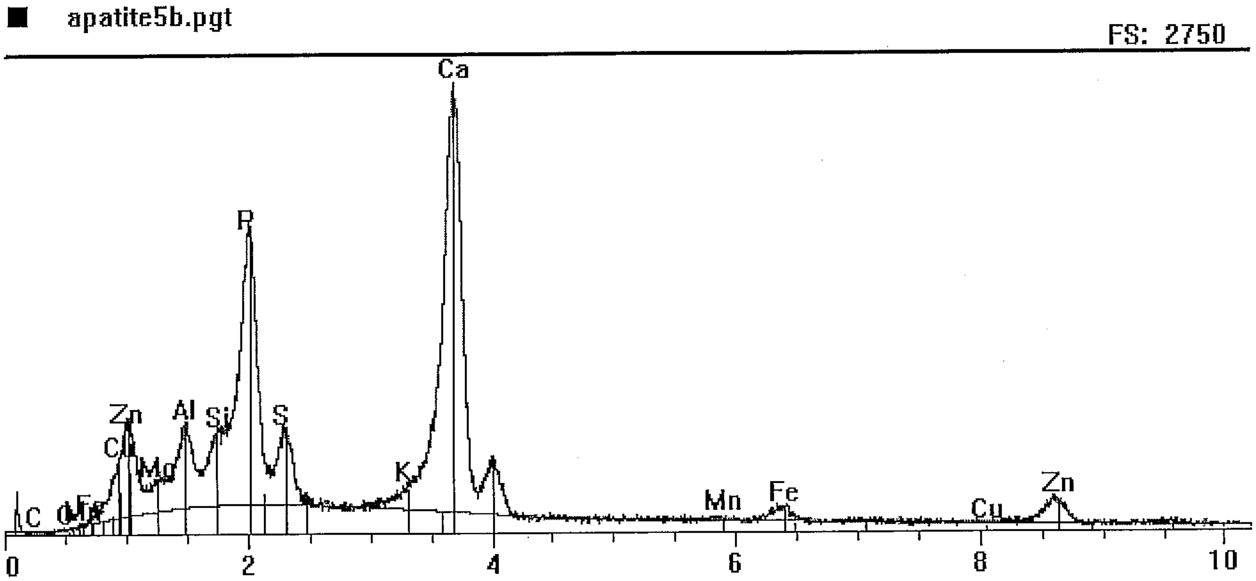
PGT
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 4 long bone close up

File: C:\Program Files\PGT\Data\vern\apatite5b.pgt
Collected: October 29, 2003 12:12:50

Live Time:	53.40	Count Rate:	8162	Dead Time:	38.62 %
Beam Voltage:	19.02	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0718	8.48	4.59	2.35
Fe	KA1	6.403	0.0212	2.48	1.57	1.44
Ca	KA1	3.691	0.3090	35.65	31.48	47.18
P	KA1	2.013	0.2085	27.83	31.81	26.28
Si	KA1	1.740	0.0386	5.33	6.72	26.28
Al	KA1	1.487	0.0373	6.02	7.90	26.28
O	KA1	0.523	0.0000	0.00	0.00	0.00
S	KA1	2.307	0.0498	7.31	8.07	26.28
Mg	KA1	1.254	0.0167	3.19	4.65	26.28
Cu	KA1	8.046	0.0015	0.18	0.10	2.35
K	KA1	3.313	0.0280	3.20	2.89	47.18
C	KA1	0.277	0.0000	0.00	0.00	0.00
Mn	KA1	5.898	0.0027	0.33	0.21	1.44
Total				**100.00**	**100.00**	**27.06**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	115.5	31.5	0.0	84.0	2.7
Fe	KA1	89.5	42.4	0.6	46.5	1.1
Ca	KA1	1298.5	76.0	6.7	1215.8	16.0
P	KA1	833.5	96.2	0.3	737.0	7.7
Si	KA1	314.8	89.0	0.3	225.6	2.5
Al	KA1	295.7	81.1	0.2	214.4	2.6
O	KA1	13.6	16.0	0.0	0.0	0.0
S	KA1	290.8	96.0	1.9	192.8	2.0
Mg	KA1	161.1	67.7	1.2	92.2	1.4
Cu	KA1	36.4	34.4	0.0	2.1	0.1
K	KA1	194.1	83.5	0.0	110.6	1.3
C	KA1	4.2	8.7	0.0	0.0	0.0
Mn	KA1	52.9	46.4	0.0	6.5	0.1

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.986	1.154	1.024	1.000	1.181	Elmnt.
Fe	KA1	0.968	1.108	1.073	0.987	1.172	Elmnt.
Ca	KA1	0.869	0.996	1.161	0.998	1.154	Elmnt.
P	KA1	0.633	0.986	1.373	0.986	1.335	Elmnt.
Si	KA1	0.853	0.948	1.493	0.975	1.380	Elmnt.
Al	KA1	0.845	0.969	1.693	0.984	1.615	Elmnt.
O	KA1	0.163	0.860	9.458	0.999	8.126	Elmnt.
S	KA1	0.687	0.966	1.544	0.984	1.468	Elmnt.
Mg	KA1	0.774	0.935	2.072	0.989	1.916	Elmnt.
Cu	KA1	0.983	1.152	1.033	0.991	1.179	Elmnt.
K	KA1	0.833	1.016	1.201	0.935	1.141	Elmnt.
C	KA1	0.029	0.817	13.376	1.000	10.920	Elmnt.
Mn	KA1	0.961	1.126	1.099	0.990	1.225	Elmnt.

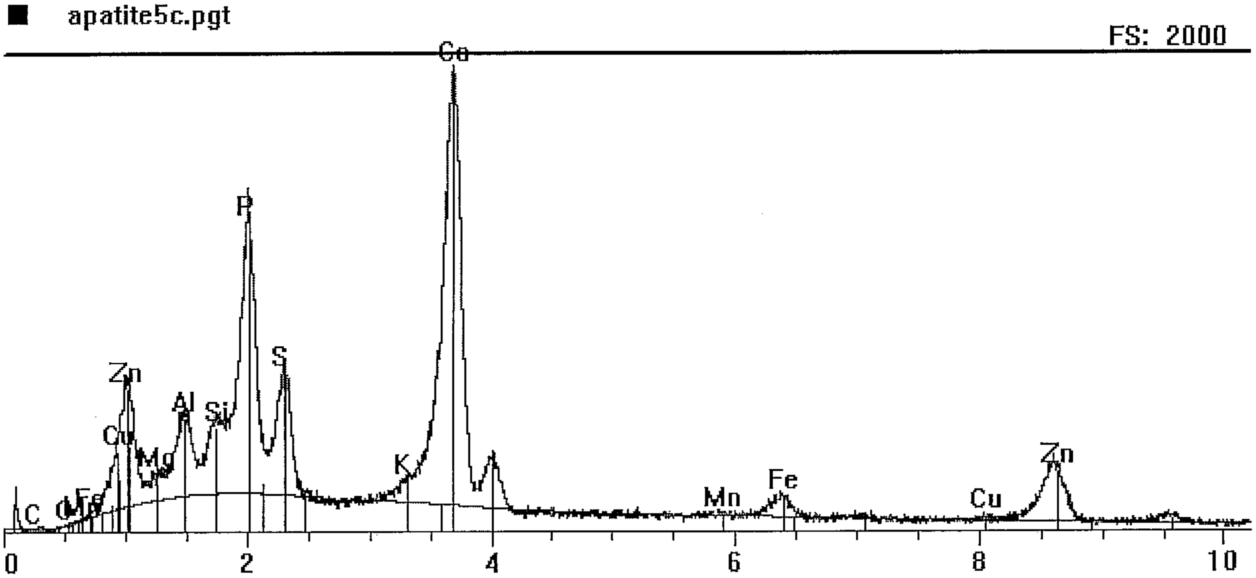
PGT
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 4 Spot on long flakey bone

File: C:\Program Files\PGT\Data\vern\apatite5c.pgt
Collected: October 29, 2003 12:12:50

Live Time:	48.96	Count Rate:	7531	Dead Time:	37.21 %
Beam Voltage:	18.99	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.1279	14.91	8.27	5.32
Fe	KA1	6.403	0.0224	2.54	1.65	1.66
Ca	KA1	3.691	0.2404	27.87	25.23	28.20
P	KA1	2.013	0.2097	28.44	33.33	12.49
Si	KA1	1.740	0.0292	4.19	5.41	12.49
Al	KA1	1.487	0.0302	5.20	7.00	12.49
O	KA1	0.523	0.0000	0.00	0.00	0.00
S	KA1	2.307	0.0759	11.30	12.79	12.49
Mg	KA1	1.254	0.0114	2.40	3.57	12.49
Cu	KA1	8.046	0.0030	0.34	0.20	5.32
K	KA1	3.313	0.0219	2.58	2.39	28.20
C	KA1	0.277	0.0000	0.00	0.00	0.00
Mn	KA1	5.898	0.0019	0.23	0.15	1.66
Total				**100.00**	**100.00**	**14.35**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	196.5	31.3	0.0	165.2	5.3
Fe	KA1	99.2	44.9	0.5	53.9	1.2
Ca	KA1	1059.8	75.8	5.4	978.6	12.9
P	KA1	675.5	100.6	0.3	574.6	5.7
Si	KA1	277.4	96.0	0.2	181.2	1.9
Al	KA1	269.6	89.3	0.2	180.2	2.0
O	KA1	13.9	16.1	0.0	0.0	0.0
S	KA1	351.0	96.6	1.6	252.8	2.6
Mg	KA1	139.3	75.3	1.2	62.7	0.8
Cu	KA1	39.5	34.9	0.0	4.5	0.1
K	KA1	168.9	81.7	0.0	87.2	1.1
C	KA1	3.5	8.3	0.0	0.0	0.0
Mn	KA1	54.2	49.1	0.0	5.1	0.1

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.978	1.142	1.020	1.000	1.166	Elmnt.
Fe	KA1	0.950	1.097	1.064	0.974	1.137	Elmnt.
Ca	KA1	0.795	0.987	1.178	0.997	1.159	Elmnt.
P	KA1	0.409	0.978	1.407	0.986	1.356	Elmnt.
Si	KA1	0.806	0.940	1.564	0.976	1.435	Elmnt.
Al	KA1	0.774	0.961	1.819	0.985	1.721	Elmnt.
O	KA1	0.039	0.852	8.356	0.999	7.116	Elmnt.
S	KA1	0.503	0.958	1.573	0.988	1.488	Elmnt.
Mg	KA1	0.675	0.927	2.289	0.991	2.101	Elmnt.
Cu	KA1	0.974	1.141	1.028	0.984	1.154	Elmnt.
K	KA1	0.738	1.007	1.231	0.950	1.178	Elmnt.
C	KA1	0.002	0.810	15.205	1.000	12.306	Elmnt.
Mn	KA1	0.938	1.116	1.087	0.981	1.191	Elmnt.

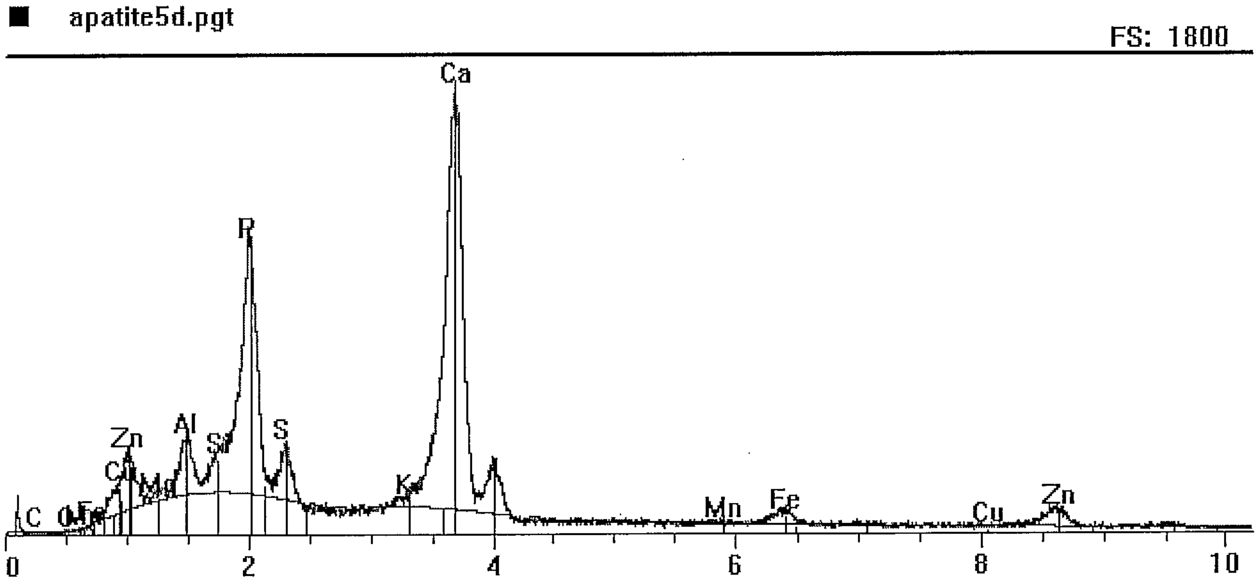
PGT
PRINCETON GAMMA·TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 4 Close-up of spot on flakey bone

File:	C:\Program Files\PGT\Data\vern\apatite5d.pgt
Collected:	October 29, 2003 12:12:50

Live Time:	32.73	Count Rate:	7572	Dead Time:	36.79 %
Beam Voltage:	18.80	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0580	6.87	3.76	1.68
Fe	KA1	6.403	0.0226	2.66	1.71	1.18
Ca	KA1	3.691	0.3434	39.41	35.18	22.97
P	KA1	2.013	0.2693	33.84	39.09	8.64
Si	KA1	1.740	0.0245	3.19	4.06	8.64
Al	KA1	1.487	0.0277	4.25	5.63	8.64
O	KA1	0.523	0.0000	0.00	0.00	0.00
S	KA1	2.307	0.0400	5.91	6.59	8.64
Mg	KA1	1.254	0.0051	0.94	1.39	8.64
Cu	KA1	8.046	0.0000	0.00	0.00	0.00
K	KA1	3.313	0.0227	2.57	2.36	22.97
C	KA1	0.277	0.0000	0.00	0.00	0.00
Mn	KA1	5.898	0.0029	0.35	0.23	1.18
Total				**100.00**	**100.00**	**12.05**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	93.9	28.7	0.0	65.2	2.3
Fe	KA1	87.2	38.8	0.6	47.8	1.2
Ca	KA1	1344.5	93.7	5.0	1245.8	13.3
P	KA1	830.6	142.2	0.2	688.2	4.8
Si	KA1	279.3	143.5	0.2	135.6	0.9
Al	KA1	282.1	134.5	0.1	147.5	1.1
O	KA1	9.2	10.4	0.0	0.0	0.0
S	KA1	245.6	121.6	1.9	122.2	1.0
Mg	KA1	137.2	111.1	0.8	25.3	0.2
Cu	KA1	29.9	31.5	0.0	0.0	0.0
K	KA1	178.8	97.9	0.0	80.9	0.8
C	KA1	3.2	8.3	0.0	0.0	0.0
Mn	KA1	49.0	42.4	0.0	6.6	0.2

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.981	1.155	1.024	1.000	1.183	Elmnt.
Fe	KA1	0.956	1.109	1.074	0.990	1.179	Elmnt.
Ca	KA1	0.816	0.997	1.154	0.998	1.148	Elmnt.
P	KA1	0.465	0.986	1.292	0.986	1.257	Elmnt.
Si	KA1	0.820	0.948	1.415	0.969	1.300	Elmnt.
Al	KA1	0.794	0.969	1.612	0.981	1.533	Elmnt.
O	KA1	0.060	0.859	9.704	0.999	8.335	Elmnt.
S	KA1	0.552	0.966	1.555	0.984	1.478	Elmnt.
Mg	KA1	0.703	0.935	1.999	0.988	1.847	Elmnt.
Cu	KA1	0.976	1.153	1.033	0.994	1.184	Elmnt.
K	KA1	0.765	1.017	1.198	0.931	1.134	Elmnt.
C	KA1	0.004	0.816	13.195	1.000	10.767	Elmnt.
Mn	KA1	0.945	1.127	1.101	0.992	1.231	Elmnt.

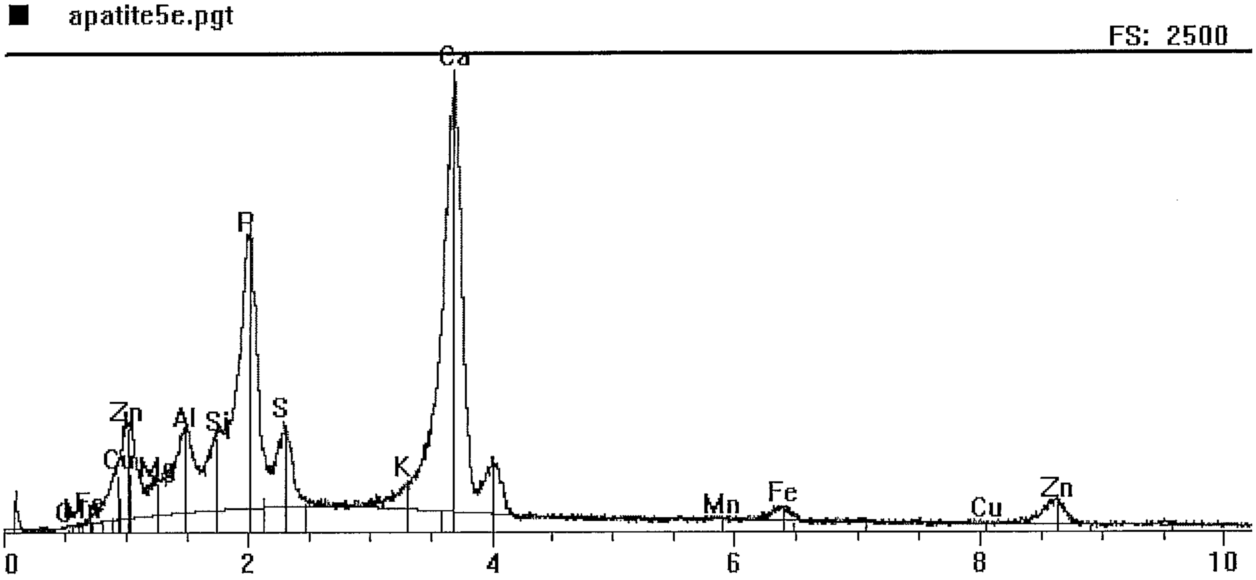
PGT
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 4 Close up of bone

File:	C:\Program Files\PGT\Data\vern\apatite5e.pgt
Collected:	October 29, 2003 12:12:50

Live Time:	47.49	Count Rate:	8314	Dead Time:	39.01 %
Beam Voltage:	19.07	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0704	8.32	4.47	1.94
Fe	KA1	6.403	0.0195	2.29	1.44	1.27
Ca	KA1	3.691	0.3062	35.41	31.07	46.50
P	KA1	2.013	0.1989	26.83	30.46	30.42
Si	KA1	1.740	0.0419	5.83	7.30	30.42
Al	KA1	1.487	0.0398	6.45	8.41	30.42
O	KA1	0.523	0.0000	0.00	0.00	0.00
S	KA1	2.307	0.0511	7.50	8.23	30.42
Mg	KA1	1.254	0.0198	3.78	5.47	30.42
Cu	KA1	8.046	0.0010	0.12	0.07	1.94
K	KA1	3.313	0.0287	3.28	2.95	46.50
Mn	KA1	5.898	0.0016	0.19	0.12	1.27
Total				**100.00**	**100.00**	**28.61**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	115.8	31.7	0.0	84.1	2.6
Fe	KA1	90.8	46.6	0.3	43.9	0.9
Ca	KA1	1325.1	74.4	7.2	1243.5	16.7
P	KA1	846.4	78.4	0.4	767.6	9.8
Si	KA1	321.2	69.9	0.3	251.0	3.6
Al	KA1	298.7	62.3	0.3	236.2	3.8
O	KA1	13.3	16.3	0.0	0.0	0.0
S	KA1	296.7	82.9	2.1	211.7	2.6
Mg	KA1	167.0	51.8	1.3	113.9	2.2
Cu	KA1	37.2	35.7	0.0	1.5	0.0
K	KA1	198.6	81.0	0.0	117.6	1.5
Mn	KA1	54.8	51.0	0.0	3.9	0.1

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.982	1.155	1.023	1.000	1.182	Elmnt.
Fe	KA1	0.960	1.109	1.073	0.987	1.174	Elmnt.
Ca	KA1	0.834	0.997	1.162	0.998	1.156	Elmnt.
P	KA1	0.516	0.987	1.386	0.986	1.349	Elmnt.
Si	KA1	0.831	0.949	1.501	0.976	1.391	Elmnt.
Al	KA1	0.811	0.970	1.696	0.984	1.619	Elmnt.
O	KA1	0.084	0.861	9.507	0.999	8.178	Elmnt.
S	KA1	0.594	0.967	1.542	0.984	1.467	Elmnt.
Mg	KA1	0.726	0.936	2.060	0.989	1.908	Elmnt.
Cu	KA1	0.979	1.153	1.032	0.991	1.180	Elmnt.
K	KA1	0.787	1.017	1.201	0.935	1.143	Elmnt.
Mn	KA1	0.950	1.128	1.099	0.990	1.227	Elmnt.

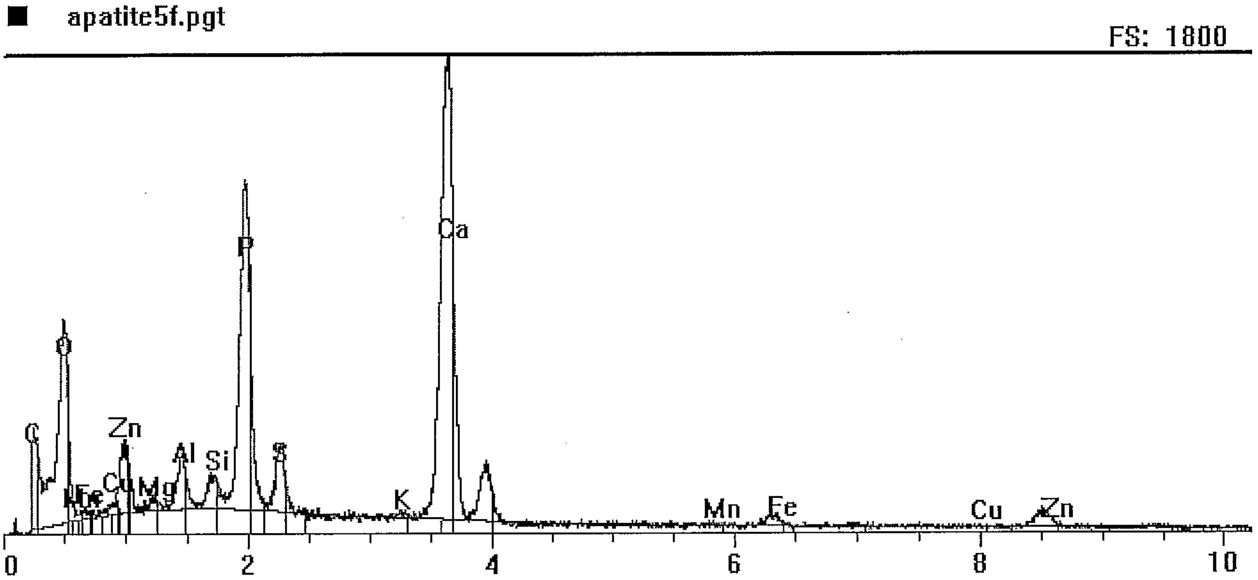
PGT
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 4 Close up of bone

File:	C:\Program Files\PGT\Data\vern\apatite5f.pgt
Collected:	October 30, 2003 11:29:41

Live Time:	1438.42	Count Rate:	143	Dead Time:	6.48 %
Beam Voltage:	18.24	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0008	0.11	0.02	7.97
Fe	KA1	6.403	0.0003	0.04	0.01	3.04
Ca	KA1	3.691	0.0083	0.97	0.33	286.96
P	KA1	2.013	0.0083	1.04	0.46	71.03
Si	KA1	1.740	0.0005	0.06	0.03	71.03
Al	KA1	1.487	0.0006	0.09	0.05	71.03
O	KA1	0.523	0.0422	41.57	35.48	71.03
S	KA1	2.307	0.0012	0.15	0.06	71.03
Mg	KA1	1.254	0.0001	0.03	0.01	71.03
Cu	KA1	8.046	0.0000	0.00	0.00	7.97
K	KA1	3.313	0.0005	0.06	0.02	286.96
C	KA1	0.277	0.3405	55.86	63.52	71.03
Mn	KA1	5.898	0.0000	0.00	0.00	3.04
Total				**100.00**	**100.00**	**117.90**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	1.1	0.5	0.0	0.7	1.4
Fe	KA1	1.1	0.6	0.0	0.5	0.8
Ca	KA1	23.6	1.2	0.1	22.4	18.7
P	KA1	16.7	1.9	0.0	14.9	7.9
Si	KA1	3.8	1.9	0.0	1.9	1.0
Al	KA1	4.3	1.9	0.0	2.4	1.3
O	KA1	9.1	0.8	0.0	8.3	10.7
S	KA1	4.5	1.7	0.0	2.7	1.6
Mg	KA1	2.3	1.7	0.0	0.5	0.3
Cu	KA1	0.5	0.5	0.0	0.0	0.1
K	KA1	2.8	1.3	0.0	1.4	1.1
C	KA1	4.4	0.3	1.3	2.7	7.9
Mn	KA1	0.7	0.7	0.0	0.1	0.1

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.985	1.413	0.986	1.000	1.393	Elmnt.
Fe	KA1	0.965	1.345	0.980	0.997	1.315	Elmnt.
Ca	KA1	0.855	1.203	0.969	1.000	1.165	Elmnt.
P	KA1	0.582	1.189	1.056	0.998	1.253	Elmnt.
Si	KA1	0.844	1.143	1.135	0.996	1.293	Elmnt.
Al	KA1	0.831	1.169	1.285	0.998	1.498	Elmnt.
O	KA1	0.125	1.038	9.483	1.000	9.842	Elmnt.
S	KA1	0.648	1.165	1.031	0.997	1.198	Elmnt.
Mg	KA1	0.754	1.127	1.553	0.999	1.749	Elmnt.
Cu	KA1	0.981	1.407	0.985	0.998	1.383	Elmnt.
K	KA1	0.814	1.226	0.972	0.984	1.173	Elmnt.
C	KA1	0.017	0.986	1.663	1.000	1.640	Elmnt.
Mn	KA1	0.956	1.366	0.980	0.998	1.335	Elmnt.

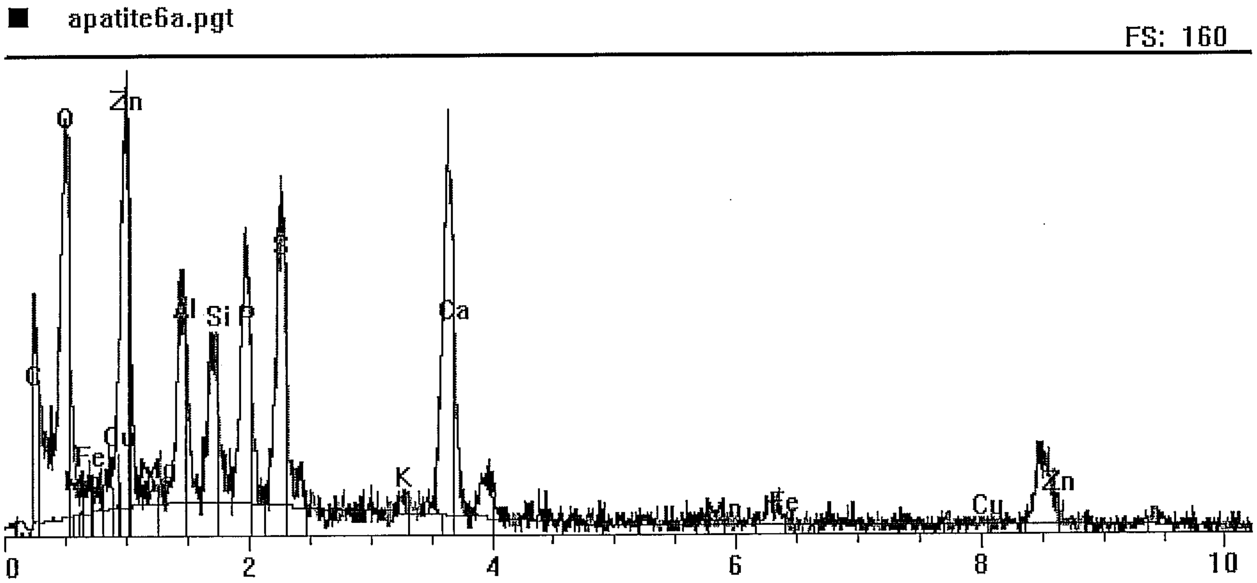
PGT
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 4 round bone, crack in bone

File:	C:\Program Files\PGT\Data\vern\apatite6a.pgt
Collected:	October 30, 2003 12:03:20

Live Time:	169.43	Count Rate:	180	Dead Time:	6.62 %
Beam Voltage:	17.55	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0118	1.57	0.34	5.20
Fe	KA1	6.403	0.0018	0.23	0.06	1.55
Ca	KA1	3.691	0.0189	2.23	0.79	15.80
P	KA1	2.013	0.0127	1.73	0.79	9.95
Si	KA1	1.740	0.0055	0.78	0.40	9.95
Al	KA1	1.487	0.0076	1.24	0.65	9.95
O	KA1	0.523	0.0522	34.06	30.13	9.95
S	KA1	2.307	0.0139	1.81	0.80	9.95
Mg	KA1	1.254	0.0009	0.18	0.10	9.95
Cu	KA1	8.046	0.0002	0.03	0.01	5.20
K	KA1	3.313	0.0018	0.21	0.08	15.80
C	KA1	0.277	0.0981	55.85	65.84	9.95
Mn	KA1	5.898	0.0005	0.06	0.02	1.55
Total				**100.00**	**100.00**	**9.15**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	2.8	0.7	0.0	2.1	2.8
Fe	KA1	1.4	0.7	0.0	0.7	1.0
Ca	KA1	14.2	1.2	0.1	12.8	10.4
P	KA1	10.8	1.9	0.0	8.8	4.6
Si	KA1	7.6	1.9	0.0	5.6	2.9
Al	KA1	9.7	1.9	0.0	7.7	4.0
O	KA1	13.8	1.0	0.0	12.8	13.3
S	KA1	11.9	1.8	0.0	10.1	5.6
Mg	KA1	2.7	1.7	0.1	0.9	0.5
Cu	KA1	0.8	0.7	0.0	0.0	0.1
K	KA1	2.6	1.4	0.0	1.2	0.9
C	KA1	6.6	0.6	1.3	4.7	7.3
Mn	KA1	0.9	0.7	0.0	0.2	0.3

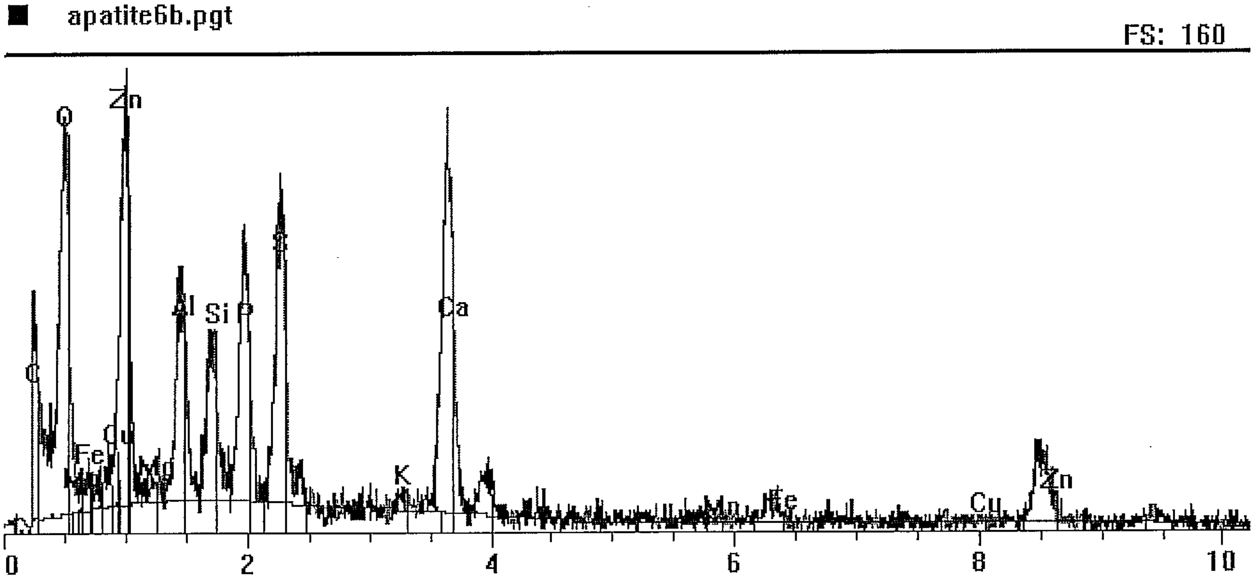
Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.989	1.336	0.996	1.000	1.331	Elmnt.
Fe	KA1	0.975	1.272	1.004	0.980	1.252	Elmnt.
Ca	KA1	0.897	1.137	1.042	0.998	1.182	Elmnt.
P	KA1	0.737	1.123	1.224	0.990	1.360	Elmnt.
Si	KA1	0.870	1.080	1.329	0.990	1.420	Elmnt.
Al	KA1	0.871	1.103	1.490	0.993	1.632	Elmnt.
O	KA1	0.269	0.978	6.673	1.000	6.522	Elmnt.
S	KA1	0.766	1.101	1.189	0.994	1.301	Elmnt.
Mg	KA1	0.812	1.064	1.849	0.995	1.956	Elmnt.
Cu	KA1	0.986	1.330	0.998	0.986	1.309	Elmnt.
K	KA1	0.868	1.159	1.064	0.974	1.201	Elmnt.
C	KA1	0.077	0.928	6.135	1.000	5.691	Elmnt.
Mn	KA1	0.969	1.292	1.010	0.986	1.286	Elmnt.

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 4 round bone, spot in crack

File:	C:\Program Files\PGT\Data\vern\apatite6b.pgt
Collected:	October 30, 2003 12:03:20

Live Time:	169.43	Count Rate:	180	Dead Time:	6.62 %
Beam Voltage:	17.55	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0118	1.57	0.34	5.20
Fe	KA1	6.403	0.0018	0.23	0.06	1.55
Ca	KA1	3.691	0.0189	2.23	0.79	15.80
P	KA1	2.013	0.0127	1.73	0.79	9.95
Si	KA1	1.740	0.0055	0.78	0.40	9.95
Al	KA1	1.487	0.0076	1.24	0.65	9.95
O	KA1	0.523	0.0522	34.06	30.13	9.95
S	KA1	2.307	0.0139	1.81	0.80	9.95
Mg	KA1	1.254	0.0009	0.18	0.10	9.95
Cu	KA1	8.046	0.0002	0.03	0.01	5.20
K	KA1	3.313	0.0018	0.21	0.08	15.80
C	KA1	0.277	0.0981	55.85	65.84	9.95
Mn	KA1	5.898	0.0005	0.06	0.02	1.55
Total				**100.00**	**100.00**	**9.15**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	2.8	0.7	0.0	2.1	2.8
Fe	KA1	1.4	0.7	0.0	0.7	1.0
Ca	KA1	14.2	1.2	0.1	12.8	10.4
P	KA1	10.8	1.9	0.0	8.8	4.6
Si	KA1	7.6	1.9	0.0	5.6	2.9
Al	KA1	9.7	1.9	0.0	7.7	4.0
O	KA1	13.8	1.0	0.0	12.8	13.3
S	KA1	11.9	1.8	0.0	10.1	5.6
Mg	KA1	2.7	1.7	0.1	0.9	0.5
Cu	KA1	0.8	0.7	0.0	0.0	0.1
K	KA1	2.6	1.4	0.0	1.2	0.9
C	KA1	6.6	0.6	1.3	4.7	7.3
Mn	KA1	0.9	0.7	0.0	0.2	0.3

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.989	1.336	0.996	1.000	1.331	Elmnt.
Fe	KA1	0.975	1.272	1.004	0.980	1.252	Elmnt.
Ca	KA1	0.897	1.137	1.042	0.998	1.182	Elmnt.
P	KA1	0.737	1.123	1.224	0.990	1.360	Elmnt.
Si	KA1	0.870	1.080	1.329	0.990	1.420	Elmnt.
Al	KA1	0.871	1.103	1.490	0.993	1.632	Elmnt.
O	KA1	0.269	0.978	6.673	1.000	6.522	Elmnt.
S	KA1	0.766	1.101	1.189	0.994	1.301	Elmnt.
Mg	KA1	0.812	1.064	1.849	0.995	1.956	Elmnt.
Cu	KA1	0.986	1.330	0.998	0.986	1.309	Elmnt.
K	KA1	0.868	1.159	1.064	0.974	1.201	Elmnt.
C	KA1	0.077	0.928	6.135	1.000	5.691	Elmnt.
Mn	KA1	0.969	1.292	1.010	0.986	1.286	Elmnt.

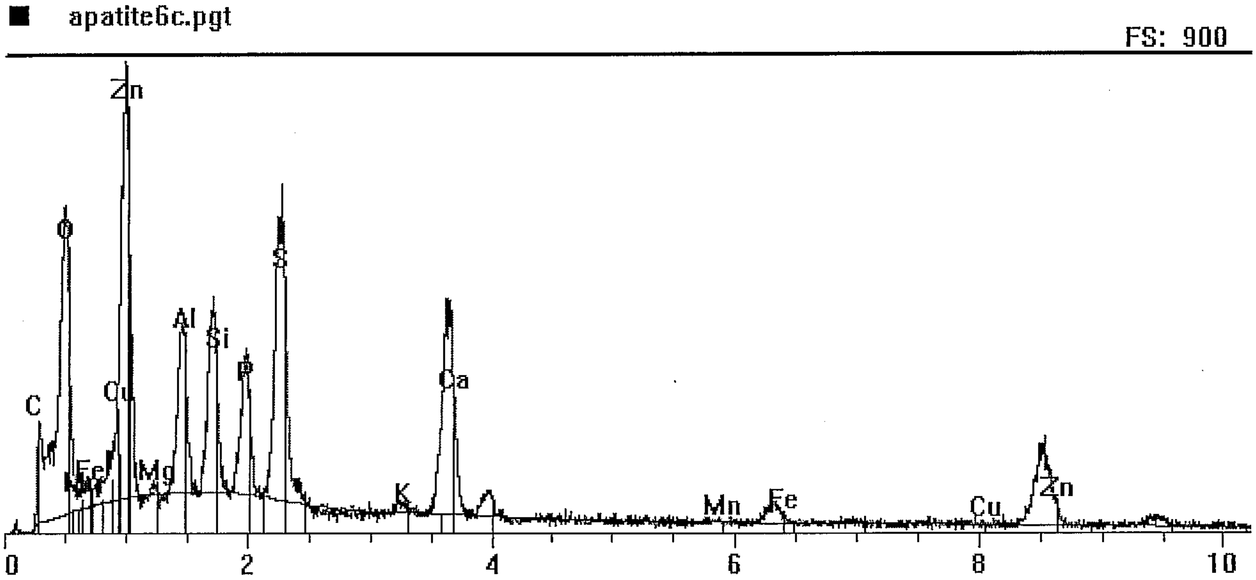
PGT
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 4 round bone, spot next to crack

File:	C:\Program Files\PGT\Data\vern\apatite6c.pgt
Collected:	October 30, 2003 12:03:20

Live Time:	372.58	Count Rate:	394	Dead Time:	7.60 %
Beam Voltage:	18.58	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0734	8.94	2.85	28.96
Fe	KA1	6.403	0.0097	1.11	0.41	2.91
Ca	KA1	3.691	0.0557	6.58	3.42	40.88
P	KA1	2.013	0.0300	4.57	3.07	41.88
Si	KA1	1.740	0.0320	5.09	3.78	41.88
Al	KA1	1.487	0.0280	5.20	4.02	41.88
O	KA1	0.523	0.1280	58.23	75.87	41.88
S	KA1	2.307	0.0678	9.52	6.19	41.88
Mg	KA1	1.254	0.0001	0.01	0.01	41.88
Cu	KA1	8.046	0.0010	0.11	0.04	28.96
K	KA1	3.313	0.0049	0.60	0.32	40.88
C	KA1	0.277	0.0000	0.00	0.00	0.00
Mn	KA1	5.898	0.0003	0.03	0.01	2.91
Total				**100.00**	**100.00**	**33.15**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	8.3	1.5	0.0	6.8	4.6
Fe	KA1	3.6	1.9	0.0	1.7	0.9
Ca	KA1	22.2	3.2	0.1	19.0	6.0
P	KA1	17.7	6.0	0.0	11.6	1.9
Si	KA1	22.1	6.2	0.0	15.9	2.5
Al	KA1	20.2	6.2	0.0	14.0	2.2
O	KA1	27.7	2.6	0.1	25.0	9.7
S	KA1	31.5	5.0	0.0	26.4	5.3
Mg	KA1	5.9	5.7	0.2	0.0	0.0
Cu	KA1	1.7	1.6	0.0	0.1	0.1
K	KA1	5.1	3.4	0.0	1.7	0.5
C	KA1	7.3	1.0	0.0	0.0	0.0
Mn	KA1	2.0	2.0	0.0	0.1	0.0

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.991	1.209	1.006	1.000	1.217	Elmnt.
Fe	KA1	0.979	1.158	1.029	0.962	1.147	Elmnt.
Ca	KA1	0.915	1.040	1.140	0.996	1.181	Elmnt.
P	KA1	0.814	1.029	1.502	0.985	1.523	Elmnt.
Si	KA1	0.881	0.989	1.628	0.988	1.591	Elmnt.
Al	KA1	0.888	1.011	1.854	0.990	1.855	Elmnt.
O	KA1	0.371	0.897	5.077	0.999	4.548	Elmnt.
S	KA1	0.822	1.008	1.401	0.994	1.404	Elmnt.
Mg	KA1	0.838	0.975	2.425	0.992	2.346	Elmnt.
Cu	KA1	0.989	1.206	1.011	0.975	1.188	Elmnt.
K	KA1	0.892	1.060	1.194	0.974	1.234	Elmnt.
C	KA1	0.142	0.851	14.186	0.999	12.071	Elmnt.
Mn	KA1	0.974	1.177	1.043	0.973	1.195	Elmnt.

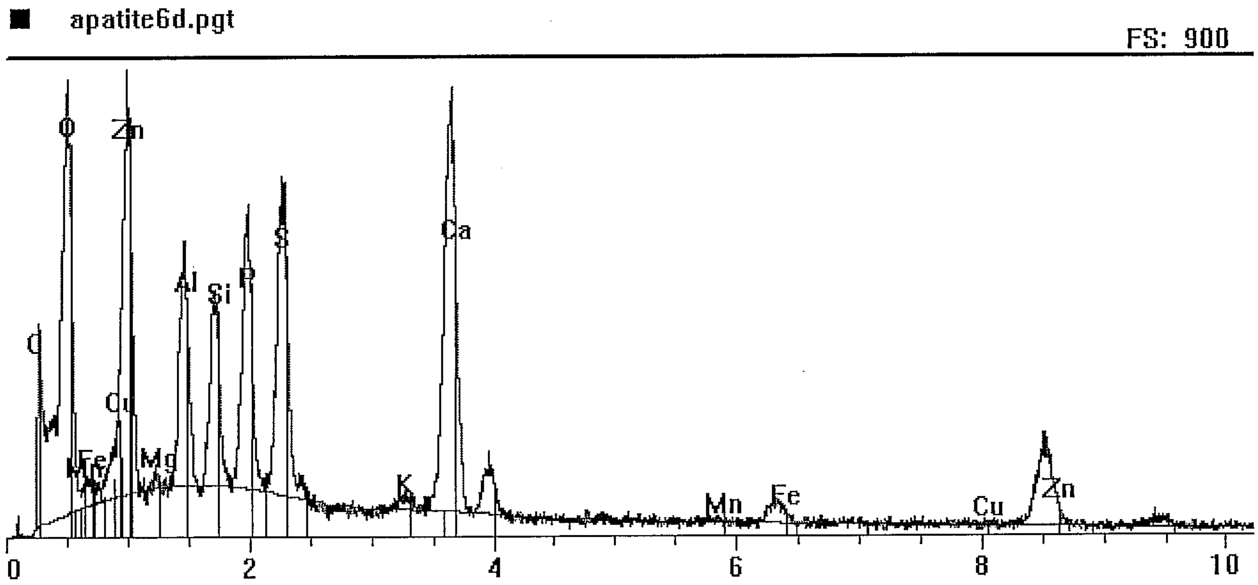
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Tank 4 round bone, close up of spot next to crack

File:	C:\Program Files\PGT\Data\vern\apatite6d.pgt
Collected:	October 30, 2003 12:03:20

Live Time:	637.53	Count Rate:	296	Dead Time:	7.15 %
Beam Voltage:	18.53	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0328	4.09	1.03	28.40
Fe	KA1	6.403	0.0052	0.62	0.18	2.94
Ca	KA1	3.691	0.0493	5.81	2.39	94.00
P	KA1	2.013	0.0265	3.85	2.05	50.62
Si	KA1	1.740	0.0145	2.22	1.30	50.62
Al	KA1	1.487	0.0169	2.99	1.83	50.62
O	KA1	0.523	0.0763	43.66	45.04	50.62
S	KA1	2.307	0.0308	4.27	2.20	50.62
Mg	KA1	1.254	0.0005	0.11	0.08	50.62
Cu	KA1	8.046	0.0006	0.07	0.02	28.40
K	KA1	3.313	0.0042	0.50	0.21	94.00
C	KA1	0.277	0.0322	31.77	43.66	50.62
Mn	KA1	5.898	0.0003	0.04	0.01	2.94
Total				**100.00**	**100.00**	**47.43**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	5.0	1.0	0.0	4.0	3.9
Fe	KA1	2.6	1.4	0.0	1.2	0.9
Ca	KA1	24.7	2.4	0.1	22.2	9.3
P	KA1	17.9	4.3	0.0	13.6	3.2
Si	KA1	14.0	4.4	0.0	9.5	2.1
Al	KA1	15.6	4.4	0.0	11.2	2.5
O	KA1	21.8	1.8	0.1	19.9	10.8
S	KA1	19.6	3.7	0.0	15.9	4.3
Mg	KA1	4.5	4.1	0.1	0.3	0.1
Cu	KA1	1.2	1.1	0.0	0.1	0.1
K	KA1	4.4	2.5	0.0	1.9	0.8
C	KA1	8.2	0.8	4.8	2.7	3.5
Mn	KA1	1.5	1.5	0.0	0.1	0.1

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.990	1.239	1.006	1.000	1.247	Elmnt.
Fe	KA1	0.977	1.186	1.030	0.974	1.189	Elmnt.
Ca	KA1	0.908	1.064	1.110	0.997	1.177	Elmnt.
P	KA1	0.785	1.052	1.400	0.987	1.453	Elmnt.
Si	KA1	0.877	1.011	1.531	0.987	1.528	Elmnt.
Al	KA1	0.882	1.034	1.727	0.990	1.768	Elmnt.
O	KA1	0.330	0.917	6.248	0.999	5.726	Elmnt.
S	KA1	0.801	1.031	1.356	0.991	1.386	Elmnt.
Mg	KA1	0.829	0.997	2.224	0.993	2.201	Elmnt.
Cu	KA1	0.988	1.236	1.010	0.983	1.227	Elmnt.
K	KA1	0.883	1.085	1.151	0.964	1.203	Elmnt.
C	KA1	0.114	0.871	11.346	0.999	9.876	Elmnt.
Mn	KA1	0.972	1.205	1.043	0.981	1.234	Elmnt.

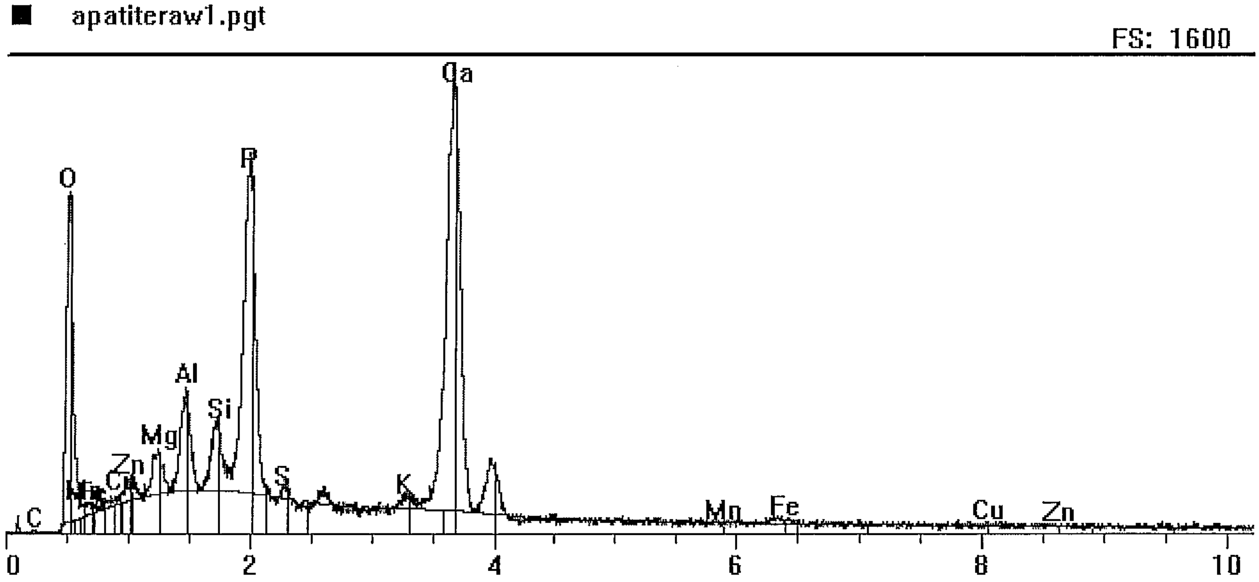
PGT
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Un-reacted bone sample

File: C:\Program Files\PGT\Data\vern\apatiteraw1.pgt
Collected: November 06, 2003 12:11:23

Live Time:	136.46	Count Rate:	1650	Dead Time:	13.95 %
Beam Voltage:	18.42	Beam Current:	2.00	Takeoff Angle:	31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0009	0.11	0.03	1.13
Fe	KA1	6.403	0.0027	0.34	0.11	0.88
Ca	KA1	3.691	0.1050	12.11	5.64	47.00
P	KA1	2.013	0.0677	9.00	5.43	26.87
Si	KA1	1.740	0.0103	1.43	0.95	26.87
Al	KA1	1.487	0.0133	2.13	1.48	26.87
O	KA1	0.523	0.1150	72.84	85.06	26.87
S	KA1	2.307	0.0013	0.18	0.11	26.87
Mg	KA1	1.254	0.0058	1.11	0.86	26.87
Cu	KA1	8.046	0.0009	0.12	0.03	1.13
K	KA1	3.313	0.0055	0.62	0.30	47.00
C	KA1	0.277	0.0000	0.00	0.00	0.00
Mn	KA1	5.898	0.0000	0.00	0.00	0.00
Total				**100.00**	**100.00**	**25.66**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	7.5	6.9	0.0	0.6	0.1
Fe	KA1	12.3	9.1	0.0	3.2	0.4
Ca	KA1	249.6	17.5	0.6	231.5	13.3
P	KA1	185.8	28.6	0.0	157.2	5.5
Si	KA1	64.1	30.7	0.0	33.4	1.1
Al	KA1	72.1	29.1	0.0	43.0	1.5
O	KA1	114.8	6.4	0.0	108.4	17.0
S	KA1	29.2	25.8	0.3	3.1	0.1
Mg	KA1	44.6	25.9	0.0	18.7	0.7
Cu	KA1	7.9	7.2	0.0	0.7	0.1
K	KA1	31.6	19.2	0.0	12.4	0.6
C	KA1	0.5	0.7	0.0	0.0	0.0
Mn	KA1	9.5	9.4	0.0	0.0	0.0

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.992	1.241	1.011	1.000	1.255	Elmnt.
Fe	KA1	0.983	1.186	1.046	0.999	1.239	Elmnt.
Ca	KA1	0.934	1.063	1.084	0.999	1.153	Elmnt.
P	KA1	0.888	1.051	1.279	0.989	1.331	Elmnt.
Si	KA1	0.840	1.011	1.398	0.979	1.383	Elmnt.
Al	KA1	0.822	1.033	1.579	0.987	1.609	Elmnt.
O	KA1	0.063	0.916	6.919	1.000	6.334	Elmnt.
S	KA1	0.877	1.030	1.404	0.984	1.423	Elmnt.
Mg	KA1	0.736	0.996	1.931	0.991	1.906	Elmnt.
Cu	KA1	0.991	1.237	1.017	1.000	1.258	Elmnt.
K	KA1	0.916	1.084	1.115	0.930	1.124	Elmnt.
C	KA1	0.003	0.870	8.826	0.999	7.669	Elmnt.
Mn	KA1	0.979	1.205	1.064	0.999	1.281	Elmnt.

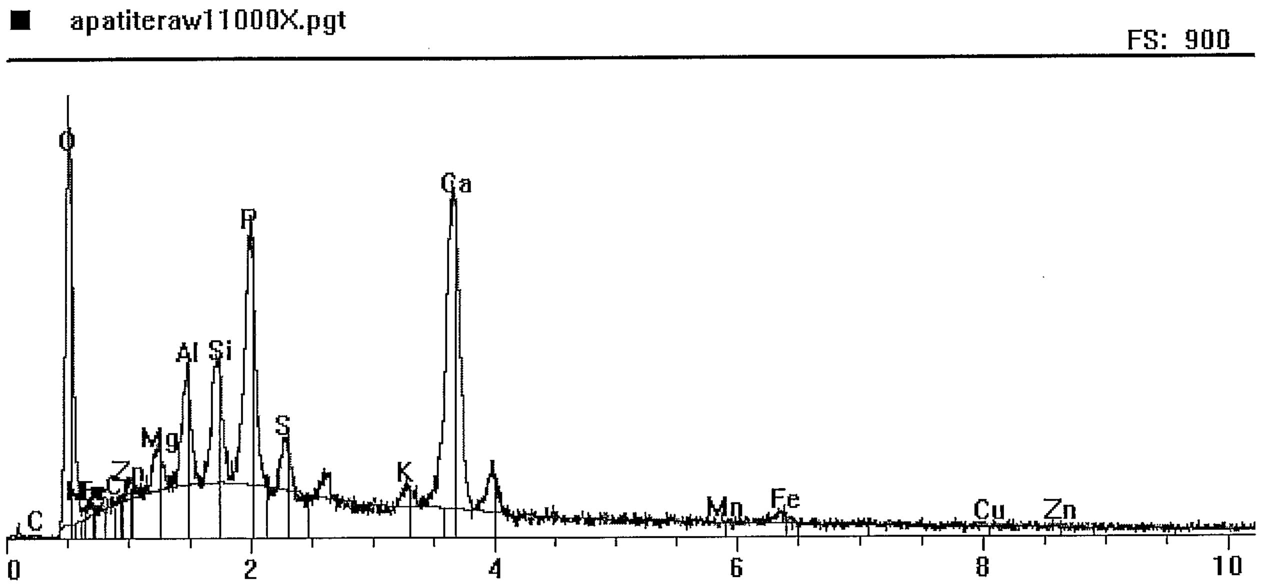
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Un-reacted bone sample

File: C:\Program Files\PGT\Data\apatiteraw11000X.pgt
Collected: November 06, 2003 12:11:23

Live Time: 281.12
Beam Voltage: 18.50
Count Rate: 501
Beam Current: 2.00
Dead Time: 8.49 %
Takeoff Angle: 31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0027	0.34	0.10	1.03
Fe	KA1	6.403	0.0065	0.79	0.27	1.14
Ca	KA1	3.691	0.0958	11.13	5.27	18.42
P	KA1	2.013	0.0541	7.59	4.65	13.83
Si	KA1	1.740	0.0223	3.16	2.14	13.83
Al	KA1	1.487	0.0179	2.92	2.05	13.83
O	KA1	0.523	0.1178	70.11	83.11	13.83
S	KA1	2.307	0.0098	1.39	0.82	13.83
Mg	KA1	1.254	0.0071	1.37	1.07	13.83
Cu	KA1	8.046	0.0023	0.29	0.09	1.03
K	KA1	3.313	0.0077	0.88	0.43	18.42
C	KA1	0.277	0.0000	0.00	0.00	0.00
Mn	KA1	5.898	0.0002	0.03	0.01	1.14
Total				**100.00**	**100.00**	**11.18**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	2.6	2.2	0.0	0.4	0.2
Fe	KA1	4.9	3.2	0.0	1.6	0.5
Ca	KA1	53.2	6.1	0.2	46.9	7.7
P	KA1	41.5	10.3	0.0	31.2	3.0
Si	KA1	26.6	10.8	0.0	15.8	1.5
Al	KA1	22.8	9.9	0.0	12.9	1.3
O	KA1	40.1	2.1	0.0	37.9	17.7
S	KA1	15.2	9.5	0.1	5.6	0.6
Mg	KA1	13.7	8.6	0.0	5.1	0.6
Cu	KA1	2.8	2.4	0.0	0.4	0.1
K	KA1	10.5	6.6	0.0	3.9	0.6
C	KA1	0.2	0.3	0.0	0.0	0.0
Mn	KA1	3.4	3.3	0.0	0.1	0.0

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.992	1.239	1.011	1.000	1.253	Elmnt.
Fe	KA1	0.983	1.185	1.042	0.997	1.231	Elmnt.
Ca	KA1	0.933	1.062	1.095	0.999	1.162	Elmnt.
P	KA1	0.886	1.050	1.351	0.989	1.404	Elmnt.
Si	KA1	0.839	1.010	1.432	0.983	1.422	Elmnt.
Al	KA1	0.819	1.032	1.599	0.987	1.629	Elmnt.
O	KA1	0.058	0.915	6.507	1.000	5.952	Elmnt.
S	KA1	0.876	1.029	1.399	0.986	1.420	Elmnt.
Mg	KA1	0.732	0.995	1.950	0.991	1.924	Elmnt.
Cu	KA1	0.991	1.235	1.017	0.999	1.255	Elmnt.
K	KA1	0.916	1.083	1.125	0.941	1.146	Elmnt.
C	KA1	0.003	0.869	9.637	0.999	8.369	Elmnt.
Mn	KA1	0.979	1.204	1.059	0.997	1.271	Elmnt.

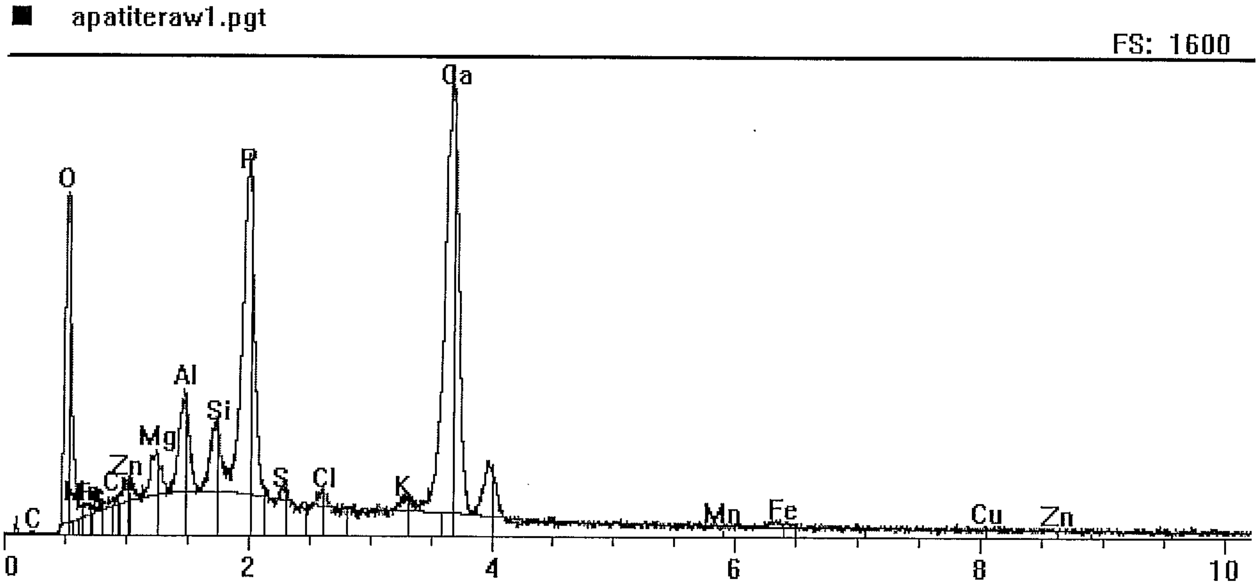
PGT
PRINCETON GAMMA-TECH

Princeton Gamma-Tech, Inc.
Spectrum Report
Monday, December 01, 2003

Un-reacted bone sample

File: C:\Program Files\PGT\Data\vern\apatiteraw1.pgt
Collected: November 06, 2003 12:11:23

Live Time: 136.46
Beam Voltage: 18.42
Count Rate: 1650
Beam Current: 2.00
Dead Time: 13.95 %
Takeoff Angle: 31.00



Element	Line	keV	KRatio	Wt%	At%	ChiSquared
Zn	KA1	8.637	0.0009	0.11	0.03	1.13
Fe	KA1	6.403	0.0026	0.32	0.11	0.88
Ca	KA1	3.691	0.1010	11.66	5.41	47.00
P	KA1	2.013	0.0662	8.80	5.29	25.47
Si	KA1	1.740	0.0099	1.37	0.91	25.47
Al	KA1	1.487	0.0127	2.05	1.42	25.47
O	KA1	0.523	0.1184	73.46	85.45	25.47
S	KA1	2.307	0.0013	0.18	0.10	25.47
Mg	KA1	1.254	0.0056	1.08	0.82	25.47
Cu	KA1	8.046	0.0009	0.11	0.03	1.13
K	KA1	3.313	0.0053	0.60	0.29	47.00
C	KA1	0.277	0.0000	0.00	0.00	0.00
Mn	KA1	5.898	0.0000	0.00	0.00	0.00
Cl	KA1	2.622	0.0019	0.26	0.13	25.47
Total				**100.00**	**100.00**	**25.59**

Element	Line	Gross (cps)	BKG (cps)	Overlap (cps)	Net (cps)	P:B Ratio
Zn	KA1	7.5	6.9	0.0	0.6	0.1
Fe	KA1	12.3	9.1	0.0	3.2	0.4
Ca	KA1	249.6	17.5	0.6	231.5	13.3
P	KA1	185.8	28.6	0.0	157.2	5.5
Si	KA1	64.1	30.7	0.0	33.4	1.1
Al	KA1	72.1	29.1	0.0	43.0	1.5
O	KA1	114.8	6.4	0.0	108.4	17.0
S	KA1	29.2	25.8	0.3	3.1	0.1
Mg	KA1	44.6	25.9	0.0	18.7	0.7
Cu	KA1	7.9	7.2	0.0	0.7	0.1
K	KA1	31.6	19.2	0.0	12.4	0.6
C	KA1	0.5	0.7	0.0	0.0	0.0
Mn	KA1	9.5	9.4	0.0	0.0	0.0
Cl	KA1	26.1	21.6	0.0	4.5	0.2

Element	Line	Det Eff	Z Corr	A Corr	F Corr	Tot Corr	Modes
Zn	KA1	0.992	1.243	1.011	1.000	1.256	Elmnt.
Fe	KA1	0.983	1.188	1.044	0.999	1.239	Elmnt.
Ca	KA1	0.933	1.065	1.085	0.999	1.155	Elmnt.
P	KA1	0.887	1.053	1.276	0.989	1.330	Elmnt.
Si	KA1	0.840	1.012	1.395	0.979	1.383	Elmnt.
Al	KA1	0.821	1.035	1.579	0.987	1.613	Elmnt.
O	KA1	0.061	0.917	6.767	1.000	6.206	Elmnt.
S	KA1	0.877	1.032	1.398	0.984	1.420	Elmnt.
Mg	KA1	0.735	0.998	1.934	0.991	1.913	Elmnt.
Cu	KA1	0.991	1.239	1.016	1.000	1.259	Elmnt.
K	KA1	0.916	1.086	1.116	0.932	1.129	Elmnt.
C	KA1	0.003	0.871	8.903	0.999	7.749	Elmnt.
Mn	KA1	0.979	1.208	1.062	0.999	1.281	Elmnt.
Cl	KA1	0.880	1.083	1.272	0.974	1.342	Elmnt.

EPA/600/R-06/153
February 2007

Mine Waste Technology Program

Permeable Treatment Wall Effectiveness Monitoring Project Nevada Stewart Mine

Appendices A through F

Appendix D

Golder Associates Geochemical Report

Golder Associates Inc.
18300 NE Union Hill Road, Suite 200
Redmond, Washington 98052
Telephone: (425) 883 0777
Fax: (425) 882 549

REPORT ON

NEVADA STEWART APATITE TREATMENT SYSTEM GEOCHEMICAL EVALUATION
NOVEMBER 2002 TO AUGUST 2004

Submitted to:

Lynn McClosky
MSE Technology Applications Inc.
P.O. Box 4078
Butte, MT 59701

Submitted by:

Golder Associates Inc.
18300 NE Union Hill Road, Suite 200
Redmond, Washington 98052

Distribution:

1	Copy -	MSE Technology Applications Inc.
2	Copies -	Golder Associates Inc.

November 4, 2004

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1.0 INTRODUCTION

This report presents the results of geochemical modeling conducted for the Nevada Stewart Mine Site Permeable Treatment Wall (Apatite II^{TM} Treatment System (ATS)). The reactive medium in the cells consists of a mixture of fish bone (Apatite II^{TM}) and gravel.

1.1 Project Background

The Nevada Stewart Mine is an abandoned lead-zinc mine located within the Coeur d'Alene Mining District, Idaho. Adit discharge from abandoned mine workings is estimated at 50 gallons per minute (gpm). Prior to installation of the subsurface ATS, adit discharge flowed into Highland Creek. The primary contaminants in adit discharge are lead, zinc and manganese (Pb, Zn and Mn).

1.2 Apatite Treatment System

The Department of Energy (DOE) constructed the ATS in September 2002. This system is described in the Quality Assurance Project Plan for the site (MSE Technology Applications Inc., 2003) (Figure 1). The system is designed to treat approximately 40% (~20 gpm) of the adit discharge, which is captured upon exiting the adit and directed to the treatment system by gravity. The ATS includes the following components:

- A 1,000-gallon retention-settling basin (Tank 1);
- Three parallel 3,000-gallon treatment tanks (Tanks 2, 3 and 4) filled with a mixture of Apatite II^{TM} and gravel (approximately 75% to 25% by volume apatite/gravel mix); and,
- An infiltration catch basin.

The remaining adit discharge (~30 gpm) bypasses the treatment system. Untreated water combines with treated water at the catch basin located downstream of the treatment system adjacent to Highland Creek. Both treated and untreated water flow under gravity from the catch basin into Highland Creek.

1.3 Performance Monitoring

1.3.1 Water Quality Monitoring

Monthly performance monitoring of the ATS system was conducted between November 2002 and August 2004[1]. Both the treatment system influent (Port 1 and Port A) and the effluent (Ports 2, 3 and 4) are monitored as well as upstream and downstream locations on Highland Creek. The two influent stations, Port 1 and Port A, are located at the inflow and the outflow of the retention basin, respectively. Port 1 is sampled at a greater frequency than Port A. Only the influent and effluent monitoring results are evaluated in this report (i.e., Ports A, 1, 2, 3 and 4).

Two levels of monitoring are conducted, described as baseline and target suites. The analytes included in each suite are summarized in Table 1. Table 2 summarizes the complete monitoring data set for 20 sampling events between November 2002 and August 2004.

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[1] Performance monitoring was not conducted in December 2002, January 2003 and January 2004. Two sampling events were conducted in April 2004 (April 1 and April 29, 2004).

To enhance tank permeability, air sparging was performed on four occasions: May 29, 2003; October 21, 2003; February 10, 2004 and April 4, 2004. Air sparging was conducted after routine monitoring.

1.3.2 Bacteriological Characterization

Total coliform analysis was conducted as part of the routine analytical suite (Table 1).

A single round of sulfate reducing bacteria (SRB) enumerations was conducted on samples collected on September 28, 2004. Samples were collected in 40 mL VOA vials from the inflow (Port 1) and outflows (Ports 2, 3 and 4) to the treatment system. SRB are a group of anaerobic bacteria which reduce sulfate to sulfide.

1.3.3 Solid Phase Characterization

Chemical analysis of the reactive medium was performed by Dr. Steve Anderson of Montana Tech of the University of Montana (Montana Tech). The results of this testing program, as they pertain to interpretation and validation of geochemical modeling, are discussed in this report. For a complete discussion of sample collection, analysis and results the reader is referred to Montana Tech's reports (Anderson and Clary, 2004; Clary, 2004).

The fish bone/gravel mixture was analyzed prior to placement in the tanks, and samples of treatment tank solids (fish bone plus gravel) were collected during tank operation on July 28, 2003. The treatment tank solids were collected at surface and from four discrete depths within each of the three treatment tanks (i.e., 8, 16, 24 and 32 inches below the surface). Samples were analyzed by Environmental Protection Agency (EPA) Test Method 3050B for the following constituents: Ca, Cd, Fe, Mn, Pb and Zn. Method 3050B involves digestion of a 1-gram (dry weight) sample with nitric acid and hydrogen peroxide. The sample fractions subjected to this analysis were biased toward the fish bone fraction of the samples (as opposed to the gravel fraction). Total metal results are therefore representative of the composition of the fish bone. Mineralogical analysis (i.e., x-ray diffraction (XRD) and scanning electron microscopy/energy dispersive x-ray spectroscopy (SEM/EDX)) was also performed by Montana Tech on the solid samples.

In September 2004, a second round of solid-phase sampling was conducted by MSE Technology Applications Inc. (MSE). Sample collection and analysis protocols (i.e., total metals analysis) were the same as those employed by Montana Tech during the July 2003 event. The metal results from the two sampling events are therefore directly comparable.

2.0 APATITE TREATMENT THEORY

Extensive research has been conducted to identify the mechanisms responsible for metals attenuation by apatite (e.g., Ma *et al.*, 1993; Ma *et al.*, 1994; Xu and Schwartz, 1994; Chen *et al.*, 1997a). Possible attenuation mechanisms include mineral precipitation, adsorption and cation substitution. The objective of the current geochemical modeling study is to obtain a greater understanding of the mechanisms responsible for metals attenuation at the Nevada Stewart Site. Performance monitoring data from twenty sampling events (November 2002 and February 2003 through August 2004) were evaluated. Because a number of constituents were omitted from the February 2003 monitoring suite, these data were not included in geochemical modeling.

The Nevada Stewart ATS uses Apatite II^{TM} as the reactive medium. Apatite II^{TM} is composed of fish bone, and therefore hydroxyapatite (nominal formula is $Ca_5(PO_4)_3(OH)$), a component of the bones and teeth of vertebrates, is the primary mineral phase.

The specific chemical composition of Apatite II^{TM} is as follows (Wright *et al.*, 2004):

$Ca_{10-x}Na_x(PO_4)_{6-x}(CO_3)_x(OH)_2$ (where x is less than 1).

In comparison to end-member hydroxyapatite, Apatite II^{TM} has partial substitution of carbonate ions for phosphate and sodium for calcium.

Bone is also composed of 30 to 35% organic material (on a dry weight basis), of which the primary constituent (95%) is collagen (Turek and Lippincott, 1985). Collagen is composed of carbon, hydrogen, nitrogen and oxygen. The nominal chemical composition of collagen can be represented by $C_{102}H_{149}O_{38}N_{31}$.

Research on metals attenuation by apatite has included testing of a variety of apatite minerals including synthetic hydroxyapatite (Ma *et al.*, 1993; Xu and Schwartz, 1994), natural apatite (Ma *et al.*, 1993; Chen *et al*, 1997) and Apatite II^{TM} (Bostick *et al.*, 2000). Mechanisms proposed for lead, cadmium and zinc attenuation by apatite are discussed below. Manganese attenuation by apatite is not specifically addressed, as this constituent appears to have received less research focus than Cd, Pb and Zn.

2.1 Lead

The dissolution of hydroxyapatite (HA) followed by the precipitation of metal phosphates and carbonates may explain the attenuation of some metals at the Nevada Stewart site. Ma and others (1993) proposed the following reaction sequence (Equations 1 and 2) to describe lead attenuation by HA:

$$Ca_{10}(PO_4)_6(OH)_{2(s)} + 14H^+_{(aq)} \leftrightarrow 10Ca^{2+}_{(aq)} + 6H_2PO^-_{4\,(aq)} + 2H_2O_{(l)} \quad \textbf{(Equation 1)}$$

$$10Pb^{2+}_{(aq)} + 6H_2PO^-_{4\,(aq)} + 2H_2O_{(l)} \leftrightarrow Pb_{10}(PO_4)_6(OH)_{2(s)} + 14H^+_{(aq)} \quad \textbf{(Equation 2)}$$

The dissolution of HA results in a release of phosphorus into solution that reacts with aqueous lead to form the lead phosphate hydroxypyromorphite (HP). The relative solubilities of HA and HP make the above reaction sequence possible, HA being the more soluble mineral phase. Modeled HA and HP solubilities in pure water as a function of pH are shown in Figure 2. As pH increases, the solubilities of HA and HP decrease. Solution pH is therefore a key factor in the effectiveness of lead attenuation by HA. Ma and others (1993) noted that for optimal lead removal, solution pH must be low enough to dissolve HA, yet high enough to maintain a low solubility of HP, thereby keeping aqueous lead concentrations low.

Subsequent work by Ma and others (1994) investigated the effects of anions in solution, specifically nitrate (NO_3^-), chloride (Cl^-), fluoride (F-), sulfate (SO_4^{2-}) and carbonate (CO_3^{2-}), on HA-lead interactions. In the presence of nitrate, sulfate and carbonate, HP was observed to form; however, in chloride and fluoride-dominated systems, chloropyromorphite (CP) [$Pb_{10}(PO_4)_6Cl_2$] and fluoropyromorphite [$Pb_{10}(PO_4)_6F_2$] precipitated, respectively. The solubility of CP relative to HA and HP is shown in Figure 2.

Research by Xu and Schwartz (1994) supports the work of Ma and others. These authors also noted the formation of HP [$Pb_5(PO_4)_3OH$] in chloride-free systems and CP when chloride was present. HP precipitation was observed to be isolated from the HA grains, whereas CP precipitated onto the HA grains. The coating of HA grains by CP is relevant with respect to the long-term dissolution and effectiveness of lead attenuation by HA. These reactions were kinetically fast (on the order of minutes), with the dissolution of HA being the rate-limiting step.

2.2 Cadmium and Zinc

Chen and others (1997b) studied reaction of cadmium and zinc solutions with apatite from a sedimentary phosphate rock deposit. Precipitation of otavite [$CdCO_3$] was observed, the carbonate being supplied by the carbonate-bearing apatite. No other cadmium or zinc mineral phases were identified; however, the possibility of other amorphous or crystalline phases (for example Cd and Zn phosphates) was not entirely dismissed. In addition to precipitation of otavite, cadmium and zinc attenuation was attributed to surface adsorption.

Ma and others (1994) studied the effects of competing metal ions, including cadmium and zinc, on lead-HA reactions. Adsorption onto HA and precipitation of amorphous to poorly crystalline phases were proposed for the observed attenuation of cadmium and zinc. A pale yellow solid was observed following reaction of HA with lead and cadmium.

3.0 EVALUATION OF MONITORING RESULTS

3.1 Influent and Effluent Chemistry

The three main contaminants in Nevada Stewart adit discharge are lead (Pb), zinc (Zn) and manganese (Mn). Inflow and outflow concentrations over the period of monitoring are summarized below:

Constituent (Dissolved Phase)	Inflow (Port 1)	Outflow (Ports 2, 3 and 4)
Lead (Pb)	0.54 to 2.1 μg/L	0.54 to 2.1 μg/L
Manganese (Mn)	0.5 to 0.7 mg/L	0.07 to 0.6 mg/L
Zinc (Zn)	5.5 to 8.0 mg/L	<0.005 to 6.1 mg/L

Observed absolute reductions in zinc concentrations are higher than for lead and manganese. Lead enters the ATS at the part per billion (ppb) level, whereas zinc concentrations in inflow waters are higher at part per million (ppm) levels. Manganese inflow concentrations are intermediate to lead and zinc.

Monitoring results are shown in Figures 3 through 13[2]. Measured inflow (Port 1) to the ATS (Figure 3) has ranged from approximately 5 to 30 gallons per minute (gpm), with peak flows being recorded in the late spring 2003 (May 2003). In February 2003, cleaning of the influent and effluent lines was required to maintain flow.

The inflow is distributed unequally between the three treatment tanks (Figure 3). Since March 2003, Port 4 has generally recorded the least outflow, ranging from less than 5% to approximately 30% of the total outflow. Between March 2003 and April 2004, with the exception of three months, Port 3 recorded the highest outflow, accounting for up to 79% of the total flow. Between June and August 2003, peak outflows were measured at Port 2. During the last four months of monitoring (May to August 2004), Port 2 also recorded the highest outflows, generally accounting for greater than 50% of the total outflow.

In summary, the apatite treatment system generally results in the following changes to adit water chemistry:

- Change from oxidizing to reducing (or less oxidizing) conditions;
- Reduction in trace metal concentrations (Cd and Zn);
- Reduction in iron and manganese;
- Small increase in calcium concentrations;
- Increase in sulfide concentrations;
- Increase in nutrient concentrations (nitrogen and phosphorus); and,
- Increase in total coliform concentrations.

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[2] Water quality monitoring was conducted twice in April 2004 (i.e., April 1 and 29). The April 29, 2004 results are not shown in Figures 3 through 13 due to the use of a monthly time step in for all graphs.

3.1.1 pH

In general, very little change in pH is observed between the influent and effluent (Figure 4). Inflow pH between November 2002 and May 2003 exhibited little variability, ranging from 6.6 to 7.0. Between May and August 2003, inflow pH demonstrated a decreasing trend, from near neutral (6.6) to slightly acidic (5.3). Influent pH increased throughout the Fall of 2003 remaining stable over the winter months at levels comparable to the winter of 2002 (i.e., pH values from 6.1 to 6.7). In 2004, pH reached a minimum in April/May, reporting levels slightly below 6.

The pH of the effluent is very stable, typically ranging from approximately 6 to 7. During a single sampling event (February 2003), the pH of Port 4 was alkaline at 8.0. The alkaline condition at Port 4 in February 2003 appears to have been an isolated occurrence. Effluent pH values from April 29, 2004 and May 25, 2004 were also anomalous in comparison to the historical record. On April 29, 2004, all outflows reported pH values lower than the inflow pH of 5.7. Outflow pH values ranged from 5.3 to 5.5. On May 25, 2004, Ports 2 and 3 reported outflow pH values slightly lower then the inflow of 5.8.

The alkalinity of effluent waters is also generally similar to alkalinity in the influent (Figure 4). The greatest differences in inflow and outflow alkalinity were observed in November 2002. Port 4 typically records higher alkalinity (up to approximately 30 mg/L) than Ports 2 and 3. The greatest differences in outflow alkalinity between Port 4 and Ports 2 and 3 were observed during the early stages of monitoring (March to October 2003) and in the final stages of monitoring (May to August 2004).

3.1.2 Redox Condition

Adit water inflow to the treatment tanks is slightly oxidized, as indicated by positive Eh values (ranging from 160 to 320 mV) and the presence of dissolved oxygen (6 to 11 mg/L) (Figure 5). Low levels of ammonia (up to 0.2 mg/L) and sulfide (typically less than 0.5 mg/L) have been recorded at Port 1. Ammonia and sulfide are reduced nitrogen and sulfur species, respectively.

The Eh of the outflow waters during the first year of monitoring indicates a change toward more reducing conditions, ranging from -90 to 230 mV. A decline in dissolved oxygen and increases in ammonia and sulfide concentrations are also indicative of more reducing conditions within the treatment tank in comparison to the influent. Since November 2003, differences between influent and effluent Eh have generally been smaller, and in some months effluent Eh values have been higher than influent Eh. Port 4 in the final stages on monitoring is an exception, reporting lower Eh values than both the influent and Ports 2 and 3. Over the period of monitoring, a general decline in effluent sulfide concentrations has also been observed. Sparging does not appear to affect effluent Eh values, that is to say, an increase in Eh is not consistently observed following sparging events.

Comparison of the three outflow water qualities indicates variability in the redox condition between tanks. Although all tank outflows show a decline in dissolved oxygen relative to the inflow, since May 2003, greater reductions in dissolved oxygen have typically been observed in Ports 2 and 4 than in Port 3 (Figure 5). Throughout 2003, Port 4 consistently recorded the highest sulfide concentrations (Figure 6). On the basis of sulfide, Port 4 would be characterized as the most reducing tank throughout 2003. Higher alkalinity in Port 4 outflow during the first year of monitoring, as mentioned earlier, is consistent with more reducing conditions in this tank. The 2004 outflow monitoring results between February and April 2004 show relatively low sulfide concentrations for all tanks ranging from below detectable limits (<0.5 mg/L) to 2 mg/L. Since May 2004, sulfide levels in Port 4 have increased, consistent with declines in Eh values.

Differences in outflow iron and manganese concentrations, other redox species, also suggest variability in redox conditions. Declines in dissolved iron and manganese are observed at all outflows; however, the magnitude of these declines is variable. Dissolved iron and manganese concentrations are generally higher in Port 3 than Ports 2 and 4, indicating a lesser degree of attenuation.

Figure 7 shows average redox species concentrations for all Ports calculated for three time periods: May through December 2003, February through April 2004 and May through August 2004. This figure illustrates that as mentioned above, throughout 2003 Port 4 was the most reducing reporting the lowest average dissolved oxygen and highest sulfide and ammonia concentrations. Data for Ports 2 and 3 indicated more oxidized environments. Port 4 average sulfide and ammonia concentrations in early 2004 were similar to those in Port 2, suggesting less variability in redox conditions between these tanks. A shift to less reducing conditions in the tanks over time would be consistent with the degradation and depletion of organic material through time. The most recent data for Port 4 show a shift back toward more reducing conditions in this tank.

SRB results from September 2004 also indicate variable redox conditions between tanks (Table 3). Port 4 reported the highest SRB concentrations in September 2004 (45 to 78 MPN/mL[3]). Port 2 reported an SRB concentration less than half that reported for Port 4. SRB were below detectable limits at the inflow (Port 1) and Port 3 outlfow. SRB concentration trends between Ports were consistent with trends in sulfide data from the August 2004 sampling event.

3.1.3 Major Ions

Calcium, magnesium and sulfate are included in the target analyte suite. Calcium concentrations in the influent are relatively stable, ranging from 83 to 103 mg/L. Effluent waters report slightly higher calcium concentrations, up to 111 mg/L (Figure 8). Monitoring results show little difference between influent and effluent magnesium concentrations on a monthly basis (typically less than 1 mg/L). The observed declines in sulfate concentrations between the influent and effluent (Figure 6) generally correlate with increases in sulfide concentrations. On a monthly basis, the sample Port that reports the greatest decline in sulfate, typically records the highest sulfide concentration (Figure 6).

3.1.4 Metals

The treatment tank appears to effectively attenuate zinc (Figure 9). Since March 2003, Port 4 has demonstrated the greatest removal efficiency (i.e., reports the lowest outflow zinc concentrations). Between March and November 2003, dissolved zinc concentrations were reduced from ppm levels to less than 15 ppb. Between November 2003 and April 2004, Port 4 effluent zinc concentrations gradually increased, coincident with a change to more oxidizing conditions (i.e., a reduction in effluent sulfide concentrations). A return to more reducing conditions in the final months of monitoring (i.e., an increase in sulfide concentrations) has resulted in a decline in effluent zinc concentrations. The effectiveness of zinc removal at Port 2 has decreased though time. Zinc in this treatment tank during the early stages of monitoring was reduced to the 10s of ppb level. Since May 2003, Port 2 zinc concentrations have ranged from 0.5 to 5 mg/L. Port 3 shows the least zinc attenuation, with outflow zinc concentrations ranging from 1 to 6 mg/L since February 2003.

A decline in cadmium concentrations is also observed; however, influent dissolved cadmium concentrations are very low (< 1 ppb) resulting in very small absolute reductions in concentration

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[3] Most Probable Number per milliliter (MPN/mL)

(Figure 9). Influent cadmium concentrations appear to vary seasonally, with peak concentrations measured in the winter and minimum concentrations measured in the summer.

No significant differences in dissolved lead concentrations are observed between inflow and outflow concentrations (Figure 9). On some dates (e.g., March, April, June and July 2003) the effluent Ports report slightly higher lead concentrations than the influent. Similar to cadmium, influent dissolved lead concentrations are very low (less than 3 ppb).

Attenuation of iron and manganese within the ATS is observed as well (Figure 10). Influent iron concentrations have ranged from 0.2 to 0.7 mg/L. As noted earlier, the three tanks show varying degrees of iron attenuation. Outflow iron concentrations range from below detectable limits (<0.01 mg/L) to 0.6 mg/L. Manganese in the influent is stable at 0.6 to 0.7 mg/L. Manganese in the effluent ranges from 0.1 to 0.6 mg/L.

3.1.5 Nutrients

Characteristic of apatite treatment systems, an increase in phosphorus concentrations is observed in the outflow (Figure 11). Total nitrogen in outflow waters is higher than in the inflow, indicating nitrogen release from the treatment medium (Figure 12). Collagen is considered the most likely nitrogen source. The highest nitrogen concentrations were reported in November 2002. In this month, ammonia was the dominant nitrogen species in all effluent waters. Between November 2002 and April 2003, the dominance of nitrate increased in all tanks. Since April 2003, ammonia has been the dominant nitrogen species in Port 4. The dominant nitrogen species in Ports 2 and 3 alternates between nitrate to ammonia. Ammonia currently dominates in all tanks.

3.1.6 Bacteriological

Inflow and outflow (typically measured at Port 4 only) total coliform concentrations are shown in Figure 13. Inflow total coliform concentrations have typically ranged from below detectable limits (< 1 per 100 mL) to less than 10 per 100 mL. The July 2004 influent total coliform concentration was anomalously high at 140 per 100 mL. An increase in total coliform is generally observed between the inflow and outflow (only three sampling events have reported a decline in total coliform). Peak outflow total coliform was measured in June 2003 at 467 per 100 mL[4]. Port 4 total coliform levels have generally declined over the period of monitoring.

The results of a single round of SRB enumerations are shown in Table 3. These results were discussed in Section 3.1.2.

3.2 Retention Basin Water Quality Results

Port 1 and Port A are located at the inflow and the outflow of the retention basin, respectively (Figure 1). Port A was sampled during three monitoring events: April 2003, October 2003 and August 2004. Port A and Port 1 water quality results for these dates are presented in Table 4[5].

The retention basin outflow quality (Port A) is similar to the inflow (Port 1). Very little change is observed in pH (< 0.2 pH units) and conductivity between the inflow and outflow (<5 µS/cm).

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[4] In March 2003, April 2003 and July 2004 Port 4 total coliform was reported by the analytical laboratory as "too numerous to count" (TNTC).

[5] Parameters measured in both Port A and Port 1 shown. Only dissolved metal concentrations are shown.

A slight decline in iron concentrations was consistently observed on all dates, possibly due to the precipitation of iron oxyhydroxides. Small declines in zinc concentrations were observed on two out of three dates. These results indicate that the retention basin results in only minor changes to the dissolved phase inflow chemistry to the three apatite treatment tanks.

3.3 Solid Phase Results

3.3.1 Elemental Composition

Solid phase chemistry results are shown in Figures 14 through 20. These graphs show both measured and calculated average concentrations for the raw Apatite II^{TM} treatment medium (fish bone) and samples collected from the active treatment tanks in July 2003 and September 2004. Average treatment tank concentrations normalized to the raw fish bone concentrations are shown in Figure 21.

Solid phase cadmium, iron, manganese, and zinc concentrations are higher in the treatment tank in comparison to the raw fish bone samples, indicating retention of these constituents within the treatment tank (Figure 21). These results were expected based on the observed reduction in aqueous phase concentrations between the inflow and outflow.

Although little change is observed between inflow and outflow aqueous lead concentrations (Figure 9), the solid phase results indicate retention of lead within the treatment tank (Figures 19 and 21).

The raw fish bone has an average magnesium content of 0.32 wt. % (Figure 17). The average magnesium content of the treatment tank samples declined from 0.25 wt. % in July 2003 to 0.12 wt. % in September 2004. The observed decrease in solid phase magnesium concentrations indicates dissolution of a magnesium-bearing phase within the treatment tank, most likely the fish bone. Release of magnesium has also been observed for the Success apatite treatment system (Golder Associates, 2003).

The raw fish bone mixture has a calcium content of approximately 20 wt. % (Figure 14). The average calcium content of samples collected from the three treatment tanks in July 2003 ranged from 20 to 22 wt. %. These results suggested that calcium released by the dissolution of apatite is re-precipitated (or adsorbed) within the treatment tanks. The September 2004 results show a decline in the average calcium content of all treatment tanks, ranging from 11 to 13 wt. %. These results indicate release of calcium from the treatment tank.

The solid phase results further suggest spatial variability in the degree of metals attenuation throughout the tanks. For example, solid phase cadmium, iron, manganese and lead concentrations all peaked at a depth of 8 inches within treatment tank 3 in July 2003. In September 2004, a distinct peak in these same constituents was observed at surface in tank 2. Spatial variability in the degree of attenuation throughout the tanks likely results from both chemical variability (e.g., spatial variability in redox conditions) as well as physical variability (e.g., preferential flow paths). Due to the small mass of sample generally subjected to total metals analysis (on the order of a few grams), observed peaks in trace metal concentrations may simply represent a micro-environment within the treatment tank. For this reason, an evaluation of average solids concentrations is likely more indicative of overall conditions and trends within the treatment tanks.

In Section 3.1.4 it was noted that Port 4 generally reports the lowest effluent zinc concentrations. The solid phase zinc results, however, show little variability in the average solid phase zinc contents of the treatment tanks. This is supported by the similarity in average monthly reduction in loading. Figure 22 shows zinc attenuation (g/day) calculated from monthly monitoring results. This evaluation shows similar average zinc attenuation rates for all tanks. The solid phase manganese contents of the September 2004 (Figure 18) samples show the same trend as the average monthly loading rates (Figure 22). It should be noted, however, that the shallow samples collected in tanks 2 and 3 have likely biased the average manganese contents of these tanks.

Pearson correlation analysis was conducted to evaluate the correlation between metals within the treatment tank solids. Constituent correlations may provide insight into the identification of attenuation mechanisms within the tanks. Correlation is a measure of the relation between two or more variables. The degree of correlation between two variables is represented by the correlation coefficient (r), which ranges in value from -1.0 to +1.0. A value of +1.0 indicates a perfect positive linear correlation, whereas a value of -1.0 is indicative of a perfect negative correlation. A positive correlation indicates that high values of one constituent occur with high values of another constituent (or conversely, that low values occur with low values). A negative correlation indicates that high values of a constituent occur with low values of another constituent. A value of 0 is indicative of no correlation between two variables. Once the possibility of a correlation between two variables is identified by a correlation coefficient close to 1 (or -1 for a negative correlation), the strength of this correlation should be checked with a scatter plot.

The September 2003 and July 2004 data sets were combined for correlation analysis. Correlation results for the treatment tank solids (30 samples) are shown in Table 5. Correlation results indicate a strong positive correlation between iron and lead ($r = 0.92$), cadmium ($r = 0.87$) and manganese ($r = 0.98$). Scatter plots of iron versus lead, manganese and cadmium (Figure 23) confirm a strong linear relationship. Positive correlations are also observed between manganese and cadmium ($r = 0.90$), manganese and lead ($r = 0.87$) and cadmium and lead ($r = 0.74$). These results suggest that these constituents (i.e., Mn, Fe, Cd and Pb) are attenuated under the same geochemical conditions. Based on the combined data (Table 5), zinc shows a poor correlation with iron ($r = 0.16$), cadmium ($r = 0.27$), manganese ($r = 0.14$) and lead ($r = 0.24$) suggesting that the attenuation mechanism for zinc is distinct from that for the other constituents. This lack of correlation is also observed in the zinc vs. iron scatter graph in Figure 23.

3.3.2 Mineralogical Analysis

Montana Tech used both XRD and SEM/EDX techniques to evaluate the mineralogy of the raw fish bone and treatment tank samples. XRD will identify crystalline phases present in a sample above the method's quantitation limit, generally a few percent. Poorly crystalline hydroxyapatite was the only phase identified by XRD in the treatment tank solids samples (Clary, 2004).

SEM/EDX analysis of the solids from all treatment tanks showed high zinc concentrations in association with high sulfide. Zinc sulfide crystals were identified in samples from treatment tank 4. The exact nature of the zinc sulfide crystals (e.g., sphalerite, wurtzite) was not determined. Identification of cadmium and lead phases was hindered by the relatively low concentrations of these metals (Clary, 2004).

4.0 GEOCHEMICAL MODELING

Geochemical modeling was conducted to identify possible reaction mechanisms responsible for changes in observed constituent concentrations. The geochemical model used in this study was PHREEQC Version 2.7 (Parkhurst and Appelo, 1999), an equilibrium speciation and mass-transfer code developed by the United States Geological Survey (USGS). This model has the ability to simulate mixing of waters, precipitation/dissolution of selected solids, redox reactions, atmospheric interaction, and adsorption of metals onto iron oxides. The MINTEQA2 thermodynamic database was selected for this project because it is considered by many in the geochemical and regulatory communities to be the most accurate geochemical database currently available. The fast reaction kinetics of hydroxyapatite dissolution (Xu and Schwartz, 1994) supports the application of an equilibrium model.

4.1 Speciation Modeling

Speciation modeling was conducted for all monitoring results for which a comprehensive chemical analysis was available (i.e., major ions and trace metals). Speciation modeling was therefore conducted at the following monitoring locations: Nevada Stewart Adit, ATS inflow (Port 1) and ATS outflows (Ports 2, 3 and 4). The limited analytical suite for Port A precluded its inclusion in geochemical modeling.

Speciation modeling was conducted with an emphasis on the following constituents for which the greatest changes (increase or decline) are observed:

Net Increase in Concentration (Treatment Tank = Source)	Net Decline in Concentration (Treatment Tank = Sink)
Calcium (Ca)	Iron (Fe)
Phosphorus (P)	Manganese (Mn)
Nitrogen (N)	Zinc (Zn)

To evaluate possible controlling mineral phases, inflow and outflow water chemistries were speciated and saturation indices evaluated. Concentrations of constituents reported as below detectable limits were assumed equal to the detection limit. The potential for mineral precipitation was assessed using the saturation index (SI) calculated according to Equation 3.

$$SI = \log (IAP/K_{sp}) \qquad \textbf{(Equation 3)}$$

The saturation index is the ratio of the ion activity product (IAP) of a mineral and the solubility product (K_{sp}). An SI greater than zero indicates that the water is supersaturated with respect to a particular mineral phase and therefore mineral precipitation may occur. Conversely, an SI less than zero suggests a propensity for a particular mineral to dissolve. Supersaturated mineral phases were identified and evaluated for their likelihood to precipitate from the solution. Saturation indices are presented in Table 6. Bolded and shaded tanks indicate near-saturation conditions, with near-saturation defined as $-0.5 \leq SI \geq +0.5$. This range was used to account for uncertainties in the thermodynamic database, as well as uncertainties inherent to collection and analysis of water samples.

4.1.1 Iron

SI values in treatment tank inflow water often indicate near-saturated conditions with respect to ferrihydrite [$Fe(OH)_3$]. Precipitation of ferrihydrite is consistent with observations of iron staining at the adit exit. Iron staining has also been observed on occasion at the outlet weirs, typically during periods of higher flow. Figure 24 shows the Port 4 outflow at two flow rates. Iron staining is observed in the photo at higher flow (photo 2). This photo was taken during a tracer experiment, which explains the blue color of the water in this photo. Outflow waters are, however, generally modeled to be undersaturated with respect to ferrihydrite. This apparent inconsistency may be indicative of redox disequilibrium. Whereas sulfide persists for some time due to slow oxidation kinetics as the reduced water equilibrates with the atmosphere upon exiting the treatment tank, iron responds more rapidly and forms a ferrihydrite precipitate. Resulting redox measurements, which are indicative of reducing conditions, represent a mixed potential (i.e. the presence of multiple redox couples) apparently dominated by the sulfide species.

Due to variability in redox potential between tanks and through time, ferrihydrite precipitation may be occurring at times in some tanks, particularly tanks 2 and 3. Table 6 shows periods of equilibrium with respect to ferrihydrite in tanks 2 and 3.

Precipitation of an iron sulfide may also be responsible for the observed decline in iron concentrations between the inflow and the outflow. Equilibrium with respect to an iron sulfide is observed during many monitoring events at Port 4 and during the early stages of monitoring at Port 2. Pyrite [FeS_2] is supersaturated in all modeled solutions due to the presence of detectable dissolved sulfide.

Equilibrium with the iron phosphate strengite [$FePO_4{:}2H_2O$] is predicted at times within all tanks. Vivianite [$Fe_3(PO_4)_2{:}8H_2O$] is modeled to be undersaturated in the outflow. Strengite and vivianite have been proposed of controls on phosphate concentrations downstream of septic systems (Zanini *et al.*, 1998; Carodona, 2000). Precipitation of a pure iron phosphate may therefore be a control on iron concentrations; however, iron substitution within a calcium phosphate phase (e.g., HA) also may occur.

4.1.2 Calcium and Phosphorus

Treatment tank inflow waters are modeled to be near-saturation to saturated with respect to HA during the early stages of monitoring. Since June 2003, SI values for HA have typically indicated undersaturated conditions. Outflow waters are generally supersaturated with respect to HA, indicative of dissolution of this mineral within the treatment tank. Bostick and others (2000) note that Apatite II™ is more soluble than crystalline hydroxyapatite, consistent with the model's prediction of supersaturation with respect to HA. Observed increases in aqueous calcium and phosphorus are consistent with dissolution of HA.

4.1.3 Zinc

Outflow waters are undersaturated with respect to zinc carbonate, hydroxide, sulfate and phosphate minerals included in the MINTEQA2 database. Equilibrium with respect to the zinc sulfide wurtzite [ZnS] is predicted in Port 2 and 4 waters on occasion, suggesting a control on zinc concentrations through mineral precipitation. Its polymorph sphalerite [ZnS] is modeled to be supersaturated in both inflow and outflow waters due to the presence of detectable dissolved sulfide in both. Mineralogical analysis by Montana Tech has identified zinc sulfide as a secondary mineral phase (Clary, 2004). A plot of effluent zinc versus sulfide shows lower zinc concentrations in association with higher sulfide, consistent with greater zinc attenuation under reducing conditions (Figure 25 – note the logarithmic scale on the ordinate).

4.1.4 Manganese

Attenuation of manganese within the treatment tank may be attributed to the precipitation of a manganese phosphate; however, further evaluation is required to establish if $MnHPO_4$ is indeed a credible secondary mineral phase. Adsorption onto ferrihydrite within the retention-settling basin may also account for manganese attenuation. Within the apatite treatment tanks where conditions are more reducing, adsorption onto ferrihydrite is considered an unlikely mechanism for manganese removal.

4.1.5 Nitrogen

As mentioned earlier, nitrogen release from the treatment tank is likely attributed to collagen. Attenuation of nitrogen by mineral precipitation is considered unlikely.

4.2 Aqueous/Solid Phase Interaction Modeling

The second phase of the geochemical modeling effort involved simulation of interactions between the solid and aqueous phase. Possible controlling mineral phases identified during speciation modeling were equilibrated with inflow water quality. The goal of this modeling was to assess the model's ability to predict outflow water quality using the standard thermodynamic database.

4.2.1 Model Approach

For selected sampling dates, the inflow chemistry (Port 1) was equilibrated with selected geochemically-credible solid phases. The resultant chemistry was then compared to measured outflow water qualities (Ports 2, 3 and 4). Specifically, the following stepwise approach was followed:

1. Settling Pond - Port 1 water quality was equilibrated with ferrihydrite. If ferrihydrite precipitated, adsorption of metals onto this mineral phase was simulated.

2. Treatment Tank – Outflow water quality from Step 1 was equilibrated with hydroxyapatite [$Ca_5(PO_4)_3OH$]. Collagen was added to solution based on the amount of nitrogen released from the treatment tank calculated as the difference between inflow and outflow total nitrogen concentrations. The following credible mineral phases were allowed to precipitate if supersaturated: $MnHPO_4$, calcite [$CaCO_3$], gypsum [$CaSO_4 \cdot 2H_2O$], galena [PbS], sphalerite [ZnS], wurtzite [ZnS] and greenockite [CdS].

3. Comparison – Predicted outflow water quality was compared to inflow water quality.

The model does not simulate adsorption of metals onto hydroxyapatite. Only adsorption onto freshly precipitated ferrihydrite is considered. Biological reactions within the treatment tank are also not represented in the modeled system.

4.2.2 Model Results

Comparisons of measured and simulated treatment tank water qualities for the April 2003 data set are provided in Figures 26 through 31. Measured concentrations are shown in black and modeled concentrations in grey. Port 1 measured water quality is representative of the water entering the settling pond (Tank 1). Port 1 outflow water quality is the predicted water quality following equilibration with ferrihydrite and metal adsorption onto this phase. These water qualities are therefore not directly comparable.

The model simulation predicts precipitation of ferrihydrite within the settling tank (Figure 27). This results in a decline in aqueous iron concentrations to values below those measured in treatment tank outflows suggesting possible over prediction of ferrihydrite precipitation by the model. Adsorption of zinc, lead, calcium, phosphate, sulfate, manganese and cadmium onto the freshly precipitated ferrihydrite is predicted as well. Reductions in concentration for all constituents through adsorption are predicted to be small ranging from less than 1 ppb (e.g., Cd and Pb) to 10s of ppb (e.g., Zn).

Precipitation of $MnHPO_4$ and cadmium, lead and zinc sulfides is predicted within the treatment tanks (Figures 29 and 30). For all four constituents (i.e. Mn, Cd, Pb and Zn), the model over-predicts the degree of attenuation within the treatment tank. Discrepancies between modeled and measured concentrations may be attributed to any one or a combination of the following:

1. The model simulation assumes equilibrium conditions and therefore does not account for the kinetics of precipitation reactions, which may result in slower formation of mineral precipitates.

2. The model assumes precipitation of pure mineral phases. In reality, most mineral phases formed will contain significant amounts of impurities. The presence of such impurities affects the thermodynamic properties and solubility characteristics of the minerals.

3. Incorrect identification of controlling mineral phases and/or a lack of thermodynamic information on minerals present in the tanks.

Good agreement is observed between the measured and modeled pH and redox conditions within the treatment tanks (Figures 26 and 29). The model accurately simulates the observed increases in alkalinity between inflow and outflow waters. This increase in alkalinity is attributed to the dissolution of hydroxyapatite. Underprediction of outflow total phosphorus (Figure 31) may be attributed to an underestimation of the amount of hydroxyapatite that dissolves or due to overestimation of the precipitation of $MnHPO_4$.

Simulated release of collagen from the treatment medium results in a change from oxidizing to reducing conditions. The model therefore reasonably simulates the distribution of sulfur between sulfate and sulfide (Figure 28). The model returns lower pe values for the treatment tanks than those recorded in the field. The occurrence of both nitrate/nitrite and sulfide in treatment tank outflows suggests a state of redox dis-equilibrium within the tanks. The ability to simulate a change from oxidizing to more reducing conditions, as observed in the field, is considered more important than obtaining an exact match between measured and modeled pe values.

5.0 SUMMARY AND CONCLUSIONS

5.1 Geochemical Modeling

An extensive geochemical data set is available for the Nevada Stewart ATS. This system effectively attenuates cadmium, lead, zinc, iron and manganese as evidenced by decreases in aqueous phase concentrations between the inflow and the outflows and increases in the solid phase concentrations of these constituents within the treatment tanks.

Geochemical modeling was conducted to identify possible attenuation mechanisms for cadmium, manganese and zinc at the Nevada Stewart ATS. Speciation modeling was first conducted to assess the potential for mineral precipitation. Speciation modeling identified manganese phosphate as a possible control on manganese concentrations. Depending on the redox conditions within each treatment tank, precipitation of ferrihydrite, iron sulfide or iron phosphate may control iron concentrations. Supersaturation is observed with respect to a number of metal sulfides (i.e., Cd, Pb and Zn).

The second phase of geochemical modeling involved simulation of the aqueous and solid phase interactions within the treatment tanks. These simulations showed good agreement between the measured and modeled geochemical conditions within the treatment tanks (e.g., pH, redox and alkalinity). Simulated release of collagen from treatment media resulted in a redox change within the treatment tanks from oxidizing to reducing conditions, as observed in the field. The chemical characteristics of the organic component of the reactive medium (tentatively identified and modeled as collagen) may merit further investigation, as its dissolution appears to have a pronounced effect on effluent quality. Good agreement was observed between modeled and observed sulfur speciation within the treatment tank. Simulated precipitation of $MnHPO_4$ and metal sulfides (i.e., CdS, PbS and ZnS) resulted in an over prediction of metal attenuation by the treatment tank.

Attenuation can likely be attributed to a variety of mechanisms including both mineral precipitation and surface reactions (e.g., adsorption). The results of geochemical modeling were reviewed in the context of the entire data set (i.e., solid phase analysis and mineralogy) and experience at other sites to identify the most likely attenuation mechanisms.

5.2 Attenuation Mechanisms

5.2.1 Sulfide Mineral Precipitation

Precipitation of zinc sulfide is likely the dominant mechanism for zinc attenuation within the treatment tanks. Some iron attenuation within the treatment tanks (in particular tank 4) may also be attributed to the precipitation of an iron sulfide. The treatment of acid mine drainage with permeable reactive barriers (PRBs) that attenuate metals by sulfide precipitation has proven successful (Benner *et al.*, 1997). In such tanks, reducing conditions are created (e.g., through use of organic substrates), resulting in formation of insoluble metal sulfides. The reducing conditions in the Nevada Stewart ATS, specifically the presence of hydrogen sulfide, suggest that metal attenuation through sulfide precipitation may also be occurring at the Nevada Stewart Site. The aqueous chemistry results support removal of zinc under reducing conditions. The lowest effluent zinc concentrations occur in association with elevated sulfide concentrations (Figure 25). Mineralogical evaluation, however, is the best way to conclusively identify controlling secondary mineral phases. Mineralogical analysis by Montana Tech has confirmed the presence of a zinc sulfide (Clary, 2004).

Attenuation of cadmium and lead due to sulfide precipitation is inconclusive. Speciation modeling shows supersaturation with respect to both cadmium and lead sulfide. The relatively low solid phase concentrations of these metals in the treatment tanks prevented the identification of any Cd/Pb secondary mineral phases by Montana Tech (Clary, 2004). Correlation analysis results for the treatment tank elemental concentrations suggest an alternative attenuation mechanism to sulfide precipitation. If the dominant mechanism for cadmium and lead removal was sulfide precipitation, a correlation between zinc and these metals would be expected. Although the early solid phase chemistry results do show a correlation between cadmium and zinc (Figure 23, Table 5), a positive correlation was not observed for the September 2004 data set. Alternative mechanisms for lead and cadmium removal are discussed in the next sections.

5.2.2 Phosphate Mineral Precipitation

Speciation modeling identified manganese phosphate as a possible control on manganese concentrations. Further evaluation is required to establish if $MnHPO_4$ is indeed a credible secondary mineral phase. Similarly, formation of strengite (Fe-phosphate) was identified as a possible sink for iron.

Effluent saturation indices indicate undersaturation with respect to HP. Because influent lead concentrations are very low, substitution of lead for calcium during re-precipitation of HA may be the mechanism responsible for lead attenuation. Precipitation of CP, which has a lower solubility than HP or HA (Figure 2), may also control lead concentrations. On the dates for which chloride data are available, saturation indices for this mineral were calculated. Chloride concentrations are generally below or close to the detection limit in site waters. The inflow is undersaturated with respect to CP. Equilibrium with CP is however predicted on occasion in both tank 2 and 3.

Co-precipitation with HA is also a possible attenuation mechanism for Cd and Fe (and possibly Mn). The positive correlations between solid phase metal concentrations for Fe, Pb, Cd and Mn suggests a similar attenuation mechanism and/or attenuation under similar geochemical conditions. Inclusion of these constituents in a secondary phosphate mineral phase is one such mechanism.

5.2.3 Surface Reactions

Adsorption of Pb, Cd and Mn onto ferrihydrite or the Apatite II^{TM} treatment medium (Wright *et al.*, 2004) would also account for the positive correlation observed between the solid phase concentrations of these metals. Iron oxide staining is observed at the adit and the treatment tank outflows. Wright (2004) cites studies that showed Apatite II^{TM} will adsorb up to 5% of its weight in metals. The mineralogical analysis conducted to date is not capable of characterizing surface reactions such as adsorption. More sophisticated analytical techniques and analysis would be required to make a definitive conclusion regarding the role of this process at the Nevada Stewart Site.

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TABLES

TABLE 1

Performance Monitoring Analytical Suite

Constituent	Ports 1 to 4		Port A
	Baseline	Target	Target
Field Parameters			
pH	x	x	x
Temperature	x	x	x
Conductivity	x	x	x
ORP/Eh	x	x	x
Dissolved Oxygen	x	x	x
General Parameters/Major Ions			
Alkalinity	x	x	
Acidity	x	x	
Calcium	x	x	x
Magnesium	x	x	
Sodium	x		
Potassium	x		
Sulfate	x	x	
Sulfide	x	x	
Chloride	x		
Fluoride	x		
Dissolved and Total Metals			
Silicon	x		
Aluminum	x		
Iron	x	x	x
Mercury	x		
Selenium	x		
Silver	x		
Thallium	x		
Cadmium	x	x	
Copper	x		
Manganese	x	x	x
Lead	x	x	
Zinc	x	x	x
Arsenic	x		
Antimony	x		
Nickel	x		
Beryllium	x		
Chromium	x		
Nutrients			
Total Ammonia	x	x	
Nitrate	x	x	
Nitrite	x	x	
Kjeldahl Nitrogen	x	x	
Dissolved Orthophosphate	x	x	
Total Phosphorus	x	x	
Dissolved Total Phosphorus	x	x	
Bacteriological			
Coliform Bacteria[a]	x	x	

[a] Coliform bacteria monitored at Port 1 and Port 4.

TABLE 2

Performance Monitoring Available Data

Date	Monitoring Location					Notes
	Port 1	Port 2	Port 3	Port 4	Port A	
18-Nov-02	B	B	B	B		Coliform (fecal) not measured at all stations.
26-Feb-03	T	T	T	T		Constituents omitted from analytical suite: Cd, Pb, P, SO_4, S, Acidity, Alkalinity, Nitrogen (all species), Coliform.
19-Mar-03	T	T	T	T		Dissolved oxygen not monitored.
23-Apr-03	T	T	T	T	T	Dissolved oxygen not monitored. Coliform not measured at all stations. Sulfide holding times exceeded. Constituents added to Port A target suite: Cd, Fe and Mg.
29-May-03	T	T	T	T		
19-Jun-03	T	T	T	T		
28-Jul-03	T	T	T	T		
19-Aug-03	T	T	T	T		
23-Sep-03	T	T	T	T		
21-Oct-03	B	B	B	B	T	Field parameters and Fe, Mn and Zn monitored at Port A as outlined in QAPP.
25-Nov-03	T	T	T	T		
22-Dec-03	T	T	T	T		
12-Feb-04	T	T	T	T		
9-Mar-04	T	T	T	T		
1-Apr-04	T	T	T	T		
29-Apr-04	T	T	T	T		
25-May-04	T	T	T	T		
22-Jun-04	T	T	T	T		
26-Jul-04	T	T	T	T		
17-Aug-04	B	B	B	B	T	

Notes:
B - Baseline
T - Target

TABLE 3

Sulfate Reducing Bacteria (SRB) Monitoring Results

	Sulfate Reducing Bacteria (SRB)	**Sulfide**
	MPN/mL	mg/L
Date	9/28/2004	8/17/2004
Port 1	<1.8	0.5
Port 2	20	0.95
Port 3	<1.8	0.59
Port 4	78	8.6
Port 4 (Duplicate)	45	-

MPN/mL - most probable number per milliltre

TABLE 4

Retention Basin Inflow and Outflow Monitoring Results

		23-Apr-03		21-Oct-03		17-Aug-04	
		Port 1	Port A	Port 1	Port A	Port 1	Port A
Field Analysis							
pH	s.u.	6.73	6.70	6.56	6.67	6.55	6.52
Temperature	°C	9.98	9.86	9.92	9.93	10.11	10.55
Conductivity	µS/cm	774	773	842	840	822	825
Eh	mV	162.2	132.6	175.5	177.5	288.5	296.4
Dissolved Oxygen	mg/L	-	-	6.50	6.21	6.85	7.95
Laboratory Analysis							
Dissolved Metals (mg/L)							
Cd	µg/L	0.53	0.56	0.46	-	0.48	-
Ca	mg/L	82.7	87.2	103	-	103	-
Fe	mg/L	0.518	0.462	0.758	0.642	0.496	0.332
Pb	µg/L	<0.63	1.3	2.1	-	1.2	-
Mg	mg/L	38.5	39.8	44.3	-	45.1	-
Mn	mg/L	0.647	0.693	0.64	0.628	0.608	0.577
Zn	mg/L	5.52	5.90	7.78	7.67	8.0	7.76

Port 1 - Retention Basin Inflow
Port A - Retention Basin Outflow

TABLE 5

Solid Metal Results - Correlation Analysis

Combined Data Set (July 2003 and September 2004) (n=30)

	Ca	Cd	Fe	Mg	Mn	Pb	Zn
Ca	1						
Cd	-0.67	1					
Fe	-0.53	**0.87**	1				
Mg	**0.95**	-0.65	-0.43	1			
Mn	-0.58	**0.90**	**0.98**	-0.50	1		
Pb	-0.51	0.74	**0.92**	-0.40	**0.87**	1	
Zn	-0.59	0.27	0.16	-0.68	0.14	0.24	1

July 2003 Data Set (n=15)

	Ca	Cd	Fe	Mg	Mn	Pb	*Zn*
Ca	1						
Cd	0.23	1					
Fe	0.07	**0.92**	1				
Mg	0.39	0.02	0.06	1			
Mn	0.16	**0.92**	**0.96**	-0.11	1		
Pb	0.04	**0.80**	**0.88**	0.14	0.79	1	
Zn	0.24	**0.82**	0.68	-0.06	0.72	0.66	1

September 2004 Data Set (n=15)

	Ca	Cd	Fe	Mg	Mn	Pb	Zn
Ca	1						
Cd	-0.74	1					
Fe	**-0.89**	**0.89**	1				
Mg	**0.84**	-0.75	**-0.82**	1			
Mn	**-0.87**	**0.91**	**0.99**	**-0.82**	1		
Pb	**-0.89**	0.76	**0.94**	-0.70	**0.92**	1	
Zn	-0.04	-0.39	-0.24	-0.13	-0.29	-0.24	1

Correlation coefficient (r) tabulated.

TABLE 6

Treatment Tank Saturation Indices

Mineral Phase		SOURCE		INFLOW																		
		Adit	Adit	Port 1	Port 1	Port 1	Port 1	Port 1	Port 1	Port 1	Port 1	Port 1	Port 1	Port 1	Port 1	Port 1	Port 1	Port 1	Port 1	Port 1	Port 1	Port 1
Date		18-Jul-02	23-Jul-02	18-Nov-02	19-Mar-03	23-Apr-03	29-May-03	19-Jun-03	28-Jul-03	19-Aug-03	23-Sep-03	21-Oct-03	25-Nov-03	22-Dec-03	10-Feb-04	9-Mar-04	1-Apr-04	1-May-04	25-May-04	22-Jun-04	26-Jul-04	17-Aug-04
Charge Balance Error (%)		2.3	2.1	6.2	-3.2	-5.4	-0.4	1.2	-0.8	-21.6	-4.3	3.1	2.4	-0.9	1.5	-3.6	0.4	-2.8	-9.0	-7.7	-5.9	-1.9
pH (s.u.)		6.8	7.0	6.8	6.8	6.7	6.6	6.1	5.4	5.3	6.4	6.6	6.7	6.3	6.2	6.1	6.4	5.7	5.8	6.8	6.8	6.6
pe		8.4	3.5	3.0	4.0	2.9	3.3	5.0	5.6	4.0	4.3	3.1	3.0	4.1	4.1	5.2	4.8	4.5	3.8	5.4	4.5	5.1
Calcite	$CaCO_3$	-0.9	-0.6	-0.9	-0.9	-1.0	-1.1	-1.5	-2.3	-2.3	-1.3	-1.1	-1.0	-1.4	-1.5	-1.6	-1.3	-1.9	-1.9	-0.9	-0.9	-1.1
Dolomite	$CaMg(CO_3)_2$	-2.0	-1.5	-2.0	-2.0	-2.2	-2.4	-3.3	-4.8	-5.5	-2.8	-2.4	-2.2	-3.1	-3.3	-3.4	-2.9	-4.1	-4.0	-2.0	-2.1	-2.4
Gypsum	$CaSO_4{:}2H_2O$	-1.1	-1.2	-1.2	-1.1	-1.2	-1.2	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.0	-1.0
Otavite	$CdCO_3$	-3.9	-3.4	-3.7	-3.5	-3.0	-3.1	-3.7	-4.4	-5.2	-3.9	-3.6	-3.1	-3.2	-3.5	-3.3	-3.3	-4.0	-4.4	-2.8	-2.9	-3.6
Greenockite	CdS	4.5	4.8	4.5	5.0	4.7	4.5	4.0	3.2	2.9	4.3	4.5	4.5	4.4	4.7	4.4	4.4	3.6	3.8	4.8	4.7	4.5
Cadmium Hydroxide	$Cd(OH)_2(A)$	-12.2	-11.4	-12.0	-11.8	-11.3	-11.6	-12.7	-14.1	-14.9	-12.5	-12.2	-11.6	-12.0	-12.4	-12.3	-12.0	-13.3	-13.6	-11.1	-11.2	-12.2
$CdSO_4$	CdSO4	-14.5	-14.3	-14.4	-14.2	-13.5	-13.6	-13.6	-13.6	-14.3	-14.1	-14.0	-13.6	-13.3	-13.6	-13.3	-13.4	-13.5	-14.0	-13.4	-13.4	-13.9
$CdSO_4{:}H_2O$	$CdSO_4{:}H_2O$	-12.7	-12.5	-12.5	-12.3	-11.7	-11.8	-11.8	-11.8	-12.5	-12.2	-12.2	-11.8	-11.5	-11.8	-11.4	-11.6	-11.7	-12.1	-11.6	-11.6	-12.1
$Cd_3(PO_4)_2$	$Cd_3(PO_4)_2$	-25.0	-23.7	-23.9	-23.8	-22.2	-22.2	-24.7	-26.8	-29.3	-22.7	-21.6	-22.7	-22.7	-24.5	-23.4	-23.2	-26.5	-26.0	-21.8	-22.0	-24.3
Fluorite	CaF_2	-1.4	-1.4	-1.4								-1.4										-1.4
Ferrihydrite	$Fe(OH)_3$	2.8	1.1	**-0.2**	0.9	**-0.5**	**-0.4**	**-0.2**	-1.7	-3.6	**0.0**	-0.7	**-0.4**	-0.6	-0.7	**-0.2**	**-0.2**	-2.0	-2.6	1.9	1.3	1.1
Siderite	$FeCO_3$	-3.8	-1.0	-1.2	-1.3	-1.4	-1.4	-1.9	-2.6	-2.7	-1.7	-1.4	-1.2	-1.8	-1.8	-2.2	-2.2	-2.6	-2.6	-1.7	-1.2	-1.6
Melanterite	$FeSO_4{:}7H_2O$	-8.0	-5.5	-5.4	-5.5	-5.5	-5.4	-5.4	-5.4	-5.5	-5.4	-5.3	-5.3	-5.4	-5.4	-5.7	-5.9	-5.7	-5.7	-5.9	-5.3	-5.5
FeS(ppt)	FeS	-4.6	-1.9	-2.3	-2.1	-3.0	-3.0	-3.5	-4.3	-3.9	-2.8	-2.5	-2.9	-3.4	-2.9	-3.8	-3.8	-4.2	-3.7	-3.4	-2.9	-2.8
Pyrite	FeS_2	26.3	19.3	17.7	20.2	16.3	16.9	19.2	18.9	16.6	19.4	17.3	16.4	17.7	18.7	19.4	18.7	17.1	16.9	20.9	19.5	21.1
Magnesite	$MgCO_3$	-1.6	-1.4	-1.6	-1.6	-1.7	-1.8	-2.3	-3.0	-3.6	-2.0	-1.8	-1.7	-2.2	-2.3	-2.3	-2.1	-2.7	-2.6	-1.6	-1.6	-1.8
Epsomite	$MgSO_4{:}7H_2O$	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-4.1	-3.5	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.5	-3.5	-3.5
Birnessite	MnO_2	-3.8	-12.9	-14.7	-12.4	-15.1	-14.7	-13.4	-15.1	-18.5	-13.6	-15.3	-15.2	-14.5	-14.7	-12.8	-12.8	-15.9	-17.0	-9.7	-11.8	-11.4
Rhodochrosite	$MnCO_3$	-1.2	-1.1	-1.3	-1.2	-1.3	-1.4	-1.9	-2.7	-2.7	-1.7	-1.5	-1.4	-1.8	-1.9	-1.9	-1.7	-2.3	-2.3	-1.3	-1.3	-1.5
Manganite	MnOOH	-0.6	-5.1	-6.2	-4.9	-6.4	-6.3	-6.1	-7.7	-9.5	-6.0	-6.7	-6.5	-6.6	-6.7	-5.8	-5.6	-7.8	-8.3	-3.6	-4.7	-4.8
$Mn_3(PO_4)_2$	$Mn_3(PO_4)_2$	-15.5	-15.1	-15.1	-15.4	-15.7	-15.5	-17.9	-20.2	-20.4	-14.7	-13.7	-16.0	-17.0	-18.0	-17.6	-17.0	-20.0	-18.4	-15.5	-15.8	-16.5
$MnHPO_4(C)$	$MnHPO_4$	1.5	1.5	1.7	1.5	1.4	1.7	1.0	0.6	0.5	2.3	2.6	1.4	1.3	0.8	1.1	1.2	**0.3**	1.1	1.5	1.4	1.3
Anglesite	$PbSO_4$	-4.2	-4.3	-4.2	-4.4	-4.5	-4.4	-3.8	-3.6	-4.0	-4.2	-3.8	-4.3	-4.0	-4.2	-3.9	-4.0	-4.1	-4.0	-4.5	-4.1	-4.0
Cerrusite	$PbCO_3$	-2.2	-2.2	-2.3	-2.6	-2.7	-2.7	-2.6	-3.1	-3.6	-2.7	-2.2	-2.6	-2.7	-2.9	-2.7	-2.6	-3.4	-3.2	-2.7	-2.4	-2.5
Galena	PbS	5.9	5.7	5.6	5.7	4.8	4.7	4.8	4.2	4.2	5.2	5.7	4.8	4.7	5.1	4.7	4.8	4.0	4.7	4.7	5.0	5.4
Hydrocerrusite	$Pb(OH)_2{:}2PbCO_3$	-9.3	-8.9	-9.6	-10.2	-10.6	-10.8	-11.0	-13.3	-14.9	-11.1	-9.4	-10.4	-11.2	-11.7	-11.2	-10.6	-13.6	-13.1	-10.6	-9.6	-10.2
Cl-Pyromorphite	$Pb_5(PO_4)_3Cl$	-1.3	-1.1	-0.8								3.0										-2.3
Hydroxypyromorphite	$Pb_5(PO_4)_3OH$	-12.2	-11.9	-11.7	-13.7	-14.3	-13.8	-14.8	-17.7	-20.4	-11.5	-8.2	-14.0	-14.4	-16.6	-14.9	-14.1	-20.0	-16.7	-14.4	-12.8	-13.5
$Pb_3(PO_4)_2$	$Pb_3(PO_4)_2$	-7.0	-6.8	-6.6	-7.8	-8.2	-7.8	-8.4	-9.9	-11.4	-6.2	-4.2	-8.0	-8.1	-9.5	-8.4	-8.0	-11.4	-9.3	-8.3	-7.3	-7.7
$PbHPO_4$	$PbHPO_4$	-4.0	-4.1	-3.8	-4.3	-4.4	-4.1	-4.2	-4.4	-4.9	-3.2	-2.6	-4.3	-4.1	-4.7	-4.2	-4.2	-5.2	-4.3	-4.5	-4.1	-4.2
Hydroxyapatite	$Ca_5(PO_4)_3OH$	0.7	1.8	1.4	0.8	**0.1**	**0.4**	-3.6	-7.6	-7.9	1.8	3.5	**0.0**	-2.0	-3.6	-3.3	-2.0	-6.9	-4.2	0.8	**0.5**	-0.7
Vivianite	$Fe_3(PO_4)2{:}8H_2O$	-11.0	-2.8	-2.8	-3.7	-3.9	-3.5	-5.8	-7.9	-8.4	-2.6	-1.4	-3.5	-4.8	-5.7	-6.4	-6.5	-8.7	-7.1	-5.0	-3.5	-4.7
FCO_3 Apatite	$Ca_{9.316}Na_{0.36}Mg_{0.144}(PO_4)_{4.8}(CO_3)_{1.2}F_{2.48}$	10.7	12.3	11.9								15.3										8.7
Strengite	$FePO_4{:}2H_2O$	1.6	**-0.3**	-0.9	**-0.3**	-1.5	-0.9	**-0.4**	-0.9	-2.7	0.5	**-0.1**	-1.4	-0.8	-1.3	**-0.4**	-0.7	-2.2	-2.0	0.7	**0.2**	**0.3**
Amorphous Silica	$SiO_2(am)$	**-0.3**	**-0.4**	**-0.4**								-0.9										-0.9
Smithsonite	$ZnCO_3$	-1.1	-0.9	-1.0	-1.0	-1.0	-1.1	-1.6	-2.3	-2.4	-1.3	-1.1	-1.0	-1.4	-1.5	-1.6	-1.3	-1.9	-1.9	-0.8	-0.9	-1.1
Sphalerite	ZnS	6.5	6.6	6.5	6.8	5.9	5.8	5.3	4.6	5.1	6.2	6.3	5.9	5.5	6.0	5.4	5.6	5.0	5.6	6.1	6.0	6.3
Wurtzite	ZnS	4.5	4.6	4.4	4.7	3.9	3.8	3.3	2.5	3.0	4.1	4.3	3.9	3.5	3.9	3.3	3.6	2.9	3.5	4.0	4.0	4.3
Zinc Hydroxide	$Zn(OH)_2(G)$	-2.7	-2.3	-2.6	-2.5	-2.7	-2.9	-3.8	-5.3	-5.4	-3.2	-2.9	-2.7	-3.5	-3.6	-3.8	-3.3	-4.5	-4.4	-2.3	-2.5	-2.9
Goslarite	$ZnSO_4{:}7H_2O$	-5.3	-5.4	-5.2	-5.2	-5.1	-5.1	-5.1	-5.1	-5.0	-5.0	-5.0	-5.0	-5.0	-5.1	-5.1	-5.0	-5.0	-5.0	-5.0	-4.9	-4.9
$Zn_3(PO_4)_2{:}4H_2O$	$Zn_3(PO_4)_2{:}4H_2O$	-5.6	-5.0	-4.7	-5.2	-5.3	-5.0	-7.2	-9.4	-9.7	-3.8	-2.8	-5.2	-6.1	-7.2	-7.0	-6.2	-9.1	-7.3	-4.6	-4.8	-5.5
Jarosite-K	$KFe_3(SO_4)_2(OH)_6$	5.5	**0.1**	-3.1								-3.9										1.5
Jarosite-Na	$NaFe_3(SO_4)_2(OH)_6$	3.1	-2.4	-5.5								-6.3										-0.9
Jarosite-H	$(H_3O)Fe_3(SO_4)_2(OH)_6$	**0.0**	-5.6	-8.6	-5.7	-9.4	-8.6	-5.9	-7.7	-12.9	-6.6	-9.2	-8.9	-7.9	-8.1	-6.1	-7.0	-10.0	-12.0	-2.6	-3.9	-3.7
Amorphous Aluminum Hydroxide	$Al(OH)_3(am)$	-1.3	-1.1	-1.6								-1.6										-1.6
Aluminum Sulphate	$Al_4(OH)_{10}SO_4$	1.5	1.2	**0.4**								0.8										0.5
Aluminum Sulphate	AlOHSO4	-3.1	-3.5	-3.3								-2.8										-2.8
Gibbsite	$Al(OH)_3$	**0.5**	0.6	**0.2**								**0.2**										**0.1**
Boehmite	AlOOH	**0.5**	0.7	**0.2**								**0.2**										**-0.1**
Millerite	NiS	**-0.1**	**0.1**	**-0.2**								**-0.2**										**-0.3**
Nickel Hydroxide	$Ni(OH)_2$	-3.2	-3.1	-3.4								-3.5										-3.6

Note: Bolded and shaded values indicate near-saturation conditions (SI of -0.5 to 0.5).

TABLE 6

Treatment Tank Saturation Indices

Mineral Phase		OUTFLOW																		
		Port 2	Port 2	Port 2	Port 2	Port 2	Port 2	Port 2	Port 2	Port 2	Port 2	Port 2	Port 2	Port 2	Port 2	Port 2	Port 2	Port 2	Port 2	Port 2
Date		18-Nov-02	19-Mar-03	23-Apr-03	29-May-03	19-Jun-03	28-Jul-03	19-Aug-03	23-Sep-03	21-Oct-03	25-Nov-03	22-Dec-03	10-Feb-04	9-Mar-04	1-Apr-04	1-May-04	25-May-04	22-Jun-04	26-Jul-04	17-Aug-04
Charge Balance Error (%)		5.9	-3.2	-1.6	-1.5	-0.9	-1.4	-2.6	-4.1	0.9	1.9	-2.8	2.0	-6.1	1.8	-6.5	-6.4	-8.3	-6.1	-3.8
pH (s.u.)		6.7	6.6	6.7	6.1	6.5	6.3	6.4	6.6	6.5	6.6	6.4	6.4	6.5	6.4	5.3	5.8	6.7	6.7	6.7
pe		-1.3	2.6	1.6	2.7	3.2	3.8	3.0	3.9	3.2	3.1	4.8	4.7	4.9	5.2	4.5	3.8	5.9	4.5	4.3
Calcite	$CaCO_3$	-0.9	-1.1	-1.0	-1.5	-1.1	-1.3	-1.3	-1.0	-1.1	-1.0	-1.2	-1.2	-1.1	-1.3	-2.4	-1.9	-1.0	-1.0	-0.9
Dolomite	$CaMg(CO_3)_2$	-2.0	-2.4	-2.2	-3.3	-2.4	-2.9	-2.8	-2.4	-2.5	-2.4	-2.8	-2.7	-2.5	-2.8	-5.0	-4.1	-2.2	-2.2	-2.2
Gypsum	$CaSO_4{:}2H_2O$	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.0	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.0	-1.0
Otavite	$CdCO_3$	-9.8	-10.3	-8.9	-5.9	-8.0	-5.4	-5.0	-4.7	-5.3	-5.1	-5.3	-7.5	-7.7	-8.5	-6.0	-5.2	-4.1	-4.4	-5.1
Greenockite	CdS	1.8	1.5	2.3	3.0	2.6	3.5	3.3	3.6	3.4	3.5	3.5	2.8	2.9	2.3	2.4	3.1	3.7	3.4	3.4
Cadmium Hydroxide	$Cd(OH)_2(A)$	-18.3	-18.8	-17.2	-14.9	-16.6	-14.2	-13.7	-13.2	-13.9	-13.7	-14.0	-16.1	-16.4	-17.3	-15.7	-14.5	-12.5	-12.8	-13.5
$CdSO_4$	CdSO4	-20.4	-20.7	-19.4	-15.9	-18.4	-15.5	-15.2	-15.1	-15.7	-15.6	-15.6	-17.8	-18.2	-18.8	-15.1	-14.7	-14.5	-14.8	-15.5
$CdSO_4{:}H_2O$	$CdSO_4{:}H_2O$	-18.6	-18.8	-17.6	-14.0	-16.6	-13.7	-13.3	-13.3	-13.8	-13.7	-13.8	-15.9	-16.3	-16.9	-13.2	-12.9	-12.7	-13.0	-13.7
$Cd_3(PO_4)_2$	$Cd_3(PO_4)_2$	-40.7	-41.6	-37.7	-29.2	-35.3	-28.0	-26.5	-24.8	-26.5	-26.8	-27.4	-33.7	-34.7	-36.4	-30.4	-28.3	-23.7	-24.6	-26.7
Fluorite	CaF_2	-1.4								-1.4										-1.4
Ferrihydrite	$Fe(OH)_3$	-5.7	-2.6	-3.6	-4.3	-2.0	-2.6	-3.2	-1.6	-1.6	-1.7	-0.6	**-0.3**	**0.2**	**0.1**	-4.8	-3.6	0.7	**0.1**	-0.6
Siderite	$FeCO_3$	-2.2	-2.8	-3.2	-3.7	-2.8	-3.5	-3.4	-3.2	-2.4	-2.5	-2.8	-2.4	-2.3	-2.3	-4.4	-3.5	-3.1	-2.2	-2.7
Melanterite	$FeSO_4{:}7H_2O$	-6.4	-6.8	-7.3	-7.2	-6.8	-7.2	-7.2	-7.2	-6.3	-6.4	-6.6	-6.2	-6.2	-6.1	-7.1	-6.6	-7.2	-6.2	-6.7
FeS(ppt)	FeS	**0.1**	**-0.4**	-1.3	-4.0	-1.5	-3.9	-4.4	-4.2	-3.0	-3.2	-3.3	-1.4	-1.0	-0.8	-5.4	-4.5	-4.6	-3.7	-3.5
Pyrite	FeS_2	14.8	22.1	18.7	15.4	21.1	17.9	15.3	17.5	17.7	17.2	20.6	23.6	25.0	25.8	16.2	16.1	20.7	18.8	19.2
Magnesite	$MgCO_3$	-1.6	-1.8	-1.7	-2.3	-1.8	-2.1	-2.0	-1.8	-1.9	-1.8	-2.0	-2.0	-1.9	-2.1	-3.1	-2.7	-1.7	-1.7	-1.7
Epsomite	$MgSO_4{:}7H_2O$	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.5	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.5	-3.5	-3.5	-3.5	-3.5
Birnessite	MnO_2	-23.9	-16.5	-17.9	-18.1	-15.6	-15.4	-16.8	-14.1	-15.9	-16.0	-13.2	-13.3	-12.4	-12.4	-17.9	-17.7	-10.2	-13.1	-13.6
Rhodochrosite	$MnCO_3$	-1.5	-1.7	-1.5	-2.1	-1.8	-2.1	-2.2	-2.0	-2.1	-2.1	-2.5	-2.3	-2.2	-2.2	-3.1	-2.8	-2.3	-2.2	-2.3
Manganite	MnOOH	-11.0	-7.4	-7.9	-8.6	-7.0	-7.2	-7.8	-6.3	-7.3	-7.3	-6.1	-6.1	-5.5	-5.7	-9.4	-8.9	-4.4	-5.9	-6.2
$Mn_3(PO_4)_2$	$Mn_3(PO_4)_2$	-14.5	-14.4	-14.2	-16.4	-15.2	-16.6	-16.6	-15.3	-15.4	-16.3	-17.3	-16.7	-16.5	-16.1	-20.4	-19.7	-16.7	-16.6	-17.0
$MnHPO_4(C)$	$MnHPO_4$	2.2	2.4	2.3	1.8	2.1	1.6	1.6	2.1	2.1	1.7	1.4	1.6	1.6	1.9	0.7	0.7	1.4	1.5	1.4
Anglesite	$PbSO_4$	-9.7	-9.9	-8.9	-4.7	-7.5	-4.2	-4.3	-4.3	-4.1	-4.4	-4.4	-7.0	-7.6	-8.0	-4.1	-4.0	-4.5	-4.1	-4.2
Cerrusite	$PbCO_3$	-7.8	-8.2	-7.1	-3.5	-5.9	-2.8	-2.8	-2.6	-2.5	-2.7	-2.9	-5.5	-5.9	-6.5	-3.8	-3.3	-2.8	-2.4	-2.5
Galena	PbS	3.5	3.2	3.8	5.1	4.4	5.8	5.2	5.4	6.0	5.6	5.7	4.5	4.4	4.0	4.2	4.7	4.8	5.1	5.7
Hydrocerrusite	$Pb(OH)_2{:}2PbCO_3$	-26.0	-27.4	-23.9	-13.8	-20.4	-11.4	-11.4	-10.6	-10.2	-10.9	-11.6	-19.4	-20.7	-22.4	-15.4	-13.3	-10.9	-9.9	-10.1
Cl-Pyromorphite	$Pb_5(PO_4)_3Cl$	-25.9								1.9										**0.4**
Hydroxypyromorphite	$Pb_5(PO_4)_3OH$	-36.9	-38.4	-33.2	-16.3	-27.2	-12.8	-12.7	-10.2	-9.3	-11.7	-12.7	-25.6	-28.1	-29.9	-19.6	-16.8	-12.0	-10.2	-10.6
$Pb_3(PO_4)_2$	$Pb_3(PO_4)_2$	-21.5	-22.4	-19.3	-9.0	-15.7	-7.0	-7.0	-5.4	-4.9	-6.4	-7.0	-14.7	-16.3	-17.2	-10.9	-9.3	-6.6	-5.5	-5.8
$PbHPO_4$	$PbHPO_4$	-8.5	-8.6	-7.7	-4.1	-6.4	-3.5	-3.5	-3.0	-2.7	-3.4	-3.5	-6.1	-6.7	-6.8	-4.5	-4.2	-3.6	-3.2	-3.3
Hydroxyapatite	$Ca_5(PO_4)_3OH$	3.4	3.4	3.4	**-0.4**	2.7	**0.5**	0.9	3.8	3.5	2.6	1.5	1.7	2.1	2.2	-6.4	-4.1	2.8	3.0	2.9
Vivianite	$Fe_3(PO_4)_2{:}8H_2O$	-4.4	-5.7	-7.0	-9.1	-6.0	-8.7	-8.5	-6.8	-4.2	-5.2	-6.2	-4.8	-4.8	-4.1	-12.3	-9.5	-7.3	-4.5	-6.1
FCO_3 Apatite	$Ca_{9.316}Na_{0.36}Mg_{0.144}(PO_4)_{4.8}(CO_3)_{1.2}F_{2.48}$	15.4								15.4										14.4
Strengite	$FePO_4{:}2H_2O$	-5.5	-2.1	-3.5	-3.5	-1.6	-2.2	-2.8	-1.1	-1.0	-1.5	**-0.2**	**0.1**	**0.4**	0.9	-3.3	-2.9	0.6	**0.2**	-0.5
Amorphous Silica	$SiO_2(am)$	-0.9								-0.9										-0.9
Smithsonite	$ZnCO_3$	-8.9	-9.9	-8.6	-2.8	-5.8	-2.2	-1.6	-1.4	-1.7	-1.7	-2.1	-4.9	-5.8	-6.5	-2.7	-2.1	-1.3	-1.3	-1.4
Sphalerite	ZnS	1.9	1.1	1.8	5.4	4.1	5.9	6.0	6.2	6.3	6.1	6.0	4.5	4.1	3.5	4.9	5.4	5.8	5.7	6.3
Wurtzite	ZnS	**-0.2**	-1.0	**-0.3**	3.4	2.0	3.9	3.9	4.2	4.2	4.1	3.9	2.5	2.0	1.5	2.9	3.4	3.7	3.7	4.3
Zinc Hydroxide	$Zn(OH)_2(G)$	-10.7	-11.7	-10.2	-5.0	-7.6	-4.3	-3.6	-3.1	-3.5	-3.5	-4.0	-6.8	-7.6	-8.5	-5.7	-4.7	-3.0	-3.1	-3.1
Goslarite	$ZnSO_4{:}7H_2O$	-13.1	-13.9	-12.7	-6.3	-9.8	-5.9	-5.4	-5.3	-5.6	-5.7	-5.9	-8.8	-9.7	-10.3	-5.3	-5.2	-5.3	-5.4	-5.4
$Zn_3(PO_4)_2{:}4H_2O$	$Zn_3(PO_4)_2{:}4H_2O$	-27.1	-29.4	-25.8	-8.8	-17.4	-7.3	-5.4	-3.6	-4.4	-5.4	-6.5	-15.0	-17.7	-19.3	-9.4	-7.8	-4.3	-4.3	-4.6
Jarosite-K	$KFe_3(SO_4)_2(OH)_6$	-19.3								-6.7										-3.7
Jarosite-Na	$NaFe_3(SO_4)_2(OH)_6$	-21.9								-9.1										-6.2
Jarosite-H	$(H_3O)Fe_3(SO_4)_2(OH)_6$	-25.0	-15.0	-18.7	-18.3	-13.2	-13.9	-15.9	-12.1	-11.9	-12.6	-8.6	-7.7	-6.8	-6.2	-16.6	-14.8	-5.6	-7.1	-9.1
Amorphous Aluminum Hydroxide	$Al(OH)_3(am)$	-1.6								-1.6										-1.5
Aluminum Sulphate	$Al_4(OH)_{10}SO_4$	**0.4**								0.7										0.6
Aluminum Sulphate	AlOHSO4	-3.2								-2.8										-3.0
Gibbsite	$Al(OH)_3$	**0.2**								**0.2**										**0.2**
Boehmite	AlOOH	**0.1**								**0.1**										**0.2**
Millerite	NiS	3.1								**0.4**										**0.2**
Nickel Hydroxide	$Ni(OH)_2$	-3.6								-3.6										-3.4

Note: Bolded and shaded values indicate near-saturation conditions (SI of -0.5 to 0.5).

TABLE 6

Treatment Tank Saturation Indices

Mineral Phase		OUTFLOW																		
		Port 3	Port 3	Port 3	Port 3	Port 3	Port 3	Port 3	Port 3	Port 3	Port 3	Port 3	Port 3	Port 3	Port 3	Port 3	Port 3	Port 3	Port 3	Port 3
Date		18-Nov-02	19-Mar-03	23-Apr-03	29-May-03	19-Jun-03	28-Jul-03	19-Aug-03	23-Sep-03	21-Oct-03	25-Nov-03	22-Dec-03	10-Feb-04	09-Mar-04	01-Apr-04	01-May-04	25-May-04	22-Jun-04	26-Jul-04	17-Aug-04
Charge Balance Error (%)		5.5	-4.8	-2.0	0.4	3.1	-1.2	-1.9	-5.2	2.7	4.5	-1.2	1.3	-4.4	-0.1	-4.3	-5.1	-7.9	-5.8	-2.9
pH (s.u.)		6.7	6.8	6.7	6.2	6.6	6.6	6.5	6.5	6.5	6.6	6.5	6.3	6.4	6.3	5.3	5.8	6.7	6.7	6.5
pe		-0.7	2.6	2.2	3.0	3.1	3.7	3.1	4.1	3.1	3.1	4.0	4.1	5.1	5.0	4.7	3.6	3.2	2.8	4.5
Calcite	$CaCO_3$	-0.6	-0.9	-1.0	-1.5	-1.0	-1.0	-1.1	-1.1	-1.1	-1.1	-1.2	-1.3	-1.2	-1.4	-2.4	-1.9	-1.0	-0.9	-1.1
Dolomite	$CaMg(CO_3)_2$	-1.5	-2.1	-2.2	-3.2	-2.3	-2.2	-2.5	-2.6	-2.6	-2.5	-2.7	-3.0	-2.8	-3.1	-5.1	-4.1	-2.2	-2.2	-2.4
Gypsum	$CaSO_4:2H_2O$	-1.3	-1.1	-1.2	-1.2	-1.1	-1.1	-1.1	-1.0	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.0	-1.0
Otavite	$CdCO_3$	-11.5	-8.1	-4.9	-4.5	-6.2	-8.9	-5.3	-4.6	-5.2	-4.9	-4.9	-4.4	-4.1	-4.2	-5.9	-4.9	-4.7	-4.4	-5.0
Greenockite	CdS	0.8	2.7	3.7	3.2	3.4	2.2	3.5	3.7	3.4	3.5	3.6	3.9	4.3	4.0	2.3	3.3	3.7	3.4	3.3
Cadmium Hydroxide	$Cd(OH)_2(A)$	-20.3	-16.4	-13.3	-13.4	-14.7	-17.4	-13.8	-13.2	-13.8	-13.4	-13.5	-13.2	-12.7	-13.0	-15.7	-14.2	-13.1	-12.8	-13.5
$CdSO_4$	CdSO4	-22.6	-18.6	-15.5	-14.5	-16.7	-19.4	-15.6	-14.8	-15.5	-15.3	-15.2	-14.6	-14.3	-14.3	-15.0	-14.4	-15.1	-14.9	-15.3
$CdSO_4:H_2O$	$CdSO_4:H_2O$	-20.8	-16.8	-13.6	-12.7	-14.8	-17.5	-13.8	-13.0	-13.7	-13.5	-13.3	-12.7	-12.5	-12.5	-13.1	-12.6	-13.3	-13.0	-13.5
$Cd_3(PO_4)_2$	$Cd_3(PO_4)_2$	-45.2	-35.6	-26.8	-25.8	-29.9	-38.2	-27.5	-24.8	-27.5	-26.1	-26.4	-25.3	-24.6	-24.8	-30.6	-27.6	-25.3	-24.6	-26.8
Fluorite	CaF_2	-1.4								-1.4										-1.4
Ferrihydrite	$Fe(OH)_3$	-7.1	-2.1	-1.6	-2.1	-0.9	**0.0**	-1.1	**-0.2**	-1.1	-2.0	-0.6	-0.8	**0.3**	**-0.5**	-4.1	-3.4	-1.2	-1.0	**-0.1**
Siderite	$FeCO_3$	-4.0	-2.8	-1.8	-2.0	-1.6	-1.4	-1.8	-1.8	-1.7	-2.8	-2.1	-2.1	-2.2	-2.6	-3.9	-3.1	-2.2	-1.6	-2.2
Melanterite	$FeSO_4:7H_2O$	-8.6	-6.9	-5.9	-5.6	-5.7	-5.5	-5.7	-5.6	-5.6	-6.7	-6.0	-5.8	-6.0	-6.2	-6.5	-6.2	-6.2	-5.6	-6.1
FeS(ppt)	FeS	-0.9	-1.4	-2.5	-3.6	-1.4	**0.4**	-2.3	-2.8	-2.4	-3.7	-3.0	-3.0	-3.2	-3.7	-4.9	-4.1	-3.1	-3.0	-3.2
Pyrite	FeS_2	16.1	20.3	16.2	15.3	20.0	24.5	18.1	19.1	17.8	16.4	18.9	18.8	20.7	19.8	17.0	16.0	17.4	16.1	19.6
Magnesite	$MgCO_3$	-1.4	-1.7	-1.7	-2.2	-1.8	-1.7	-1.9	-1.9	-1.9	-1.9	-2.0	-2.1	-2.0	-2.2	-3.2	-2.7	-1.7	-1.7	-1.8
Epsomite	$MgSO_4:7H_2O$	-3.8	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.5	-3.5	-3.6	-3.6	-3.6	-3.6	-3.6	-3.5	-3.5	-3.5	-3.5	-3.5
Birnessite	MnO_2	-22.8	-15.6	-16.5	-17.1	-15.7	-14.2	-15.7	-13.8	-15.7	-15.9	-14.2	-14.5	-11.9	-12.7	-17.6	-17.9	-15.6	-16.3	-13.2
Rhodochrosite	$MnCO_3$	-1.4	-1.4	-1.4	-1.9	-1.8	-1.6	-1.7	-1.7	-1.7	-2.1	-2.0	-2.0	-1.7	-1.9	-3.1	-2.7	-2.2	-2.1	-2.0
Manganite	MnOOH	-10.5	-6.7	-7.1	-8.0	-7.1	-6.2	-7.0	-6.0	-7.0	-7.2	-6.4	-6.6	-5.1	-5.7	-9.2	-9.0	-7.2	-7.5	-6.0
$Mn_3(PO_4)_2$	$Mn_3(PO_4)_2$	-13.4	-14.1	-14.7	-16.6	-15.2	-14.9	-15.3	-14.7	-15.3	-16.2	-16.1	-16.6	-16.0	-16.2	-20.5	-19.5	-16.3	-16.2	-16.4
$MnHPO_4(C)$	$MnHPO_4$	2.9	2.3	2.0	1.6	2.1	2.1	1.9	2.3	1.9	1.7	1.7	1.5	1.6	1.7	0.7	0.7	1.6	1.7	1.6
Anglesite	$PbSO_4$	-11.9	-7.9	-4.6	-4.3	-5.5	-8.5	-4.5	-4.2	-4.1	-4.3	-4.2	-4.2	-4.0	-4.0	-4.1	-4.0	-4.5	-4.1	-4.1
Cerrusite	$PbCO_3$	-9.6	-6.1	-2.8	-2.9	-3.8	-6.7	-2.9	-2.7	-2.5	-2.6	-2.6	-2.8	-2.5	-2.6	-3.8	-3.3	-2.8	-2.4	-2.5
Galena	PbS	2.5	4.3	5.6	4.5	5.5	4.1	5.5	5.3	5.8	5.4	5.5	5.2	5.5	5.3	4.1	4.7	5.3	5.1	5.5
Hydrocerrusite	$Pb(OH)_2:2PbCO_3$	-31.9	-20.9	-10.9	-12.0	-14.1	-22.9	-11.5	-10.9	-10.4	-10.7	-10.7	-11.5	-10.5	-10.9	-15.6	-13.3	-11.1	-9.8	-10.2
Cl-Pyromorphite	$Pb_5(PO_4)_3Cl$	-34.2								**-0.2**										**0.0**
Hydroxypyromorphite	$Pb_5(PO_4)_3OH$	-45.2	-28.7	-13.0	-14.6	-17.0	-31.9	-13.2	-11.2	-11.4	-11.5	-11.9	-13.6	-12.4	-12.4	-20.2	-17.2	-11.9	-10.0	-11.2
$Pb_3(PO_4)_2$	$Pb_3(PO_4)_2$	-26.4	-16.7	-7.3	-8.2	-9.6	-18.5	-7.3	-6.0	-6.3	-6.3	-6.6	-7.5	-6.9	-6.8	-11.2	-9.6	-6.5	-5.4	-6.1
$PbHPO_4$	$PbHPO_4$	-9.8	-6.9	-3.9	-4.0	-4.4	-7.5	-3.7	-3.2	-3.4	-3.4	-3.5	-3.8	-3.7	-3.5	-4.6	-4.3	-3.5	-3.1	-3.4
Hydroxyapatite	$Ca_5(PO_4)_3OH$	5.9	3.3	2.0	-1.3	2.7	2.7	1.6	2.5	1.4	2.3	1.3	**-0.2**	**0.0**	**-0.3**	-7.1	-4.5	3.2	3.2	1.9
Vivianite	$Fe_3(PO_4)2:8H_2O$	-8.9	-6.2	-3.9	-4.8	-2.8	-2.3	-3.4	-2.8	-3.4	-6.2	-4.6	-4.8	-5.5	-6.3	-11.0	-8.6	-4.3	-2.6	-5.0
FCO_3 Apatite	$Ca_{9.316}Na_{0.36}Mg_{0.144}(PO_4)_{4.8}(CO_3)_{1.2}F_{2.48}$	19.6								12.0										12.7
Strengite	$FePO_4:2H_2O$	-6.2	-2.3	-2.0	-1.8	-0.6	**0.1**	-1.0	**0.3**	-1.0	-1.9	-0.5	-0.7	**0.1**	**-0.3**	-2.7	-2.8	-1.0	-0.9	**-0.1**
Amorphous Silica	$SiO_2(am)$	-0.9								-0.9										-0.9
Smithsonite	$ZnCO_3$	-11.1	-5.3	-1.3	-1.6	-3.6	-6.4	-1.8	-1.4	-1.4	-1.5	-1.4	-1.5	-1.4	-1.5	-2.6	-2.0	-1.5	-1.4	-1.3
Sphalerite	ZnS	0.5	4.7	6.5	5.4	5.2	3.9	6.2	6.2	6.4	6.2	6.3	6.1	6.2	6.0	4.9	5.5	6.1	5.7	6.2
Wurtzite	ZnS	-1.5	2.6	4.4	3.3	3.2	1.9	4.2	4.1	4.4	4.1	4.2	4.0	4.1	3.9	2.9	3.4	4.1	3.6	4.1
Zinc Hydroxide	$Zn(OH)_2(G)$	-13.1	-6.9	-3.0	-3.8	-5.4	-8.2	-3.6	-3.2	-3.3	-3.2	-3.3	-3.5	-3.3	-3.5	-5.7	-4.6	-3.2	-3.1	-3.2
Goslarite	$ZnSO_4:7H_2O$	-15.7	-9.4	-5.5	-5.2	-7.6	-10.5	-5.7	-5.2	-5.3	-5.4	-5.3	-5.2	-5.2	-5.1	-5.2	-5.1	-5.5	-5.4	-5.2
$Zn_3(PO_4)_2:4H_2O$	$Zn_3(PO_4)_2:4H_2O$	-32.8	-16.2	-5.0	-6.1	-11.0	-19.6	-5.9	-4.0	-4.9	-4.7	-4.9	-5.6	-5.4	-5.4	-9.5	-7.9	-4.6	-4.5	-4.7
Jarosite-K	$KFe_3(SO_4)_2(OH)_6$	-23.6								-5.0										-2.1
Jarosite-Na	$NaFe_3(SO_4)_2(OH)_6$	-26.4								-7.4										-4.6
Jarosite-H	$(H_3O)Fe_3(SO_4)_2(OH)_6$	-29.6	-14.5	-12.7	-12.1	-10.1	-7.4	-10.3	-7.3	-10.2	-13.4	-8.9	-8.8	-6.0	-7.7	-14.4	-14.2	-11.0	-10.3	-7.4
Amorphous Aluminum Hydroxide	$Al(OH)_3(am)$	-1.6								-1.6										-1.6
Aluminum Sulphate	$Al_4(OH)_{10}SO_4$	**0.3**								0.9										0.5
Aluminum Sulphate	AlOHSO4	-3.3								-2.7										-2.8
Gibbsite	$Al(OH)_3$	**0.2**								**0.2**										**0.1**
Boehmite	AlOOH	**0.1**								**0.2**										**0.1**
Millerite	NiS	4.0								**0.2**										**-0.2**
Nickel Hydroxide	$Ni(OH)_2$	-3.7								-3.6										-3.7

Note: Bolded and shaded values indicate near-saturation conditions (SI of -0.5 to 0.5).

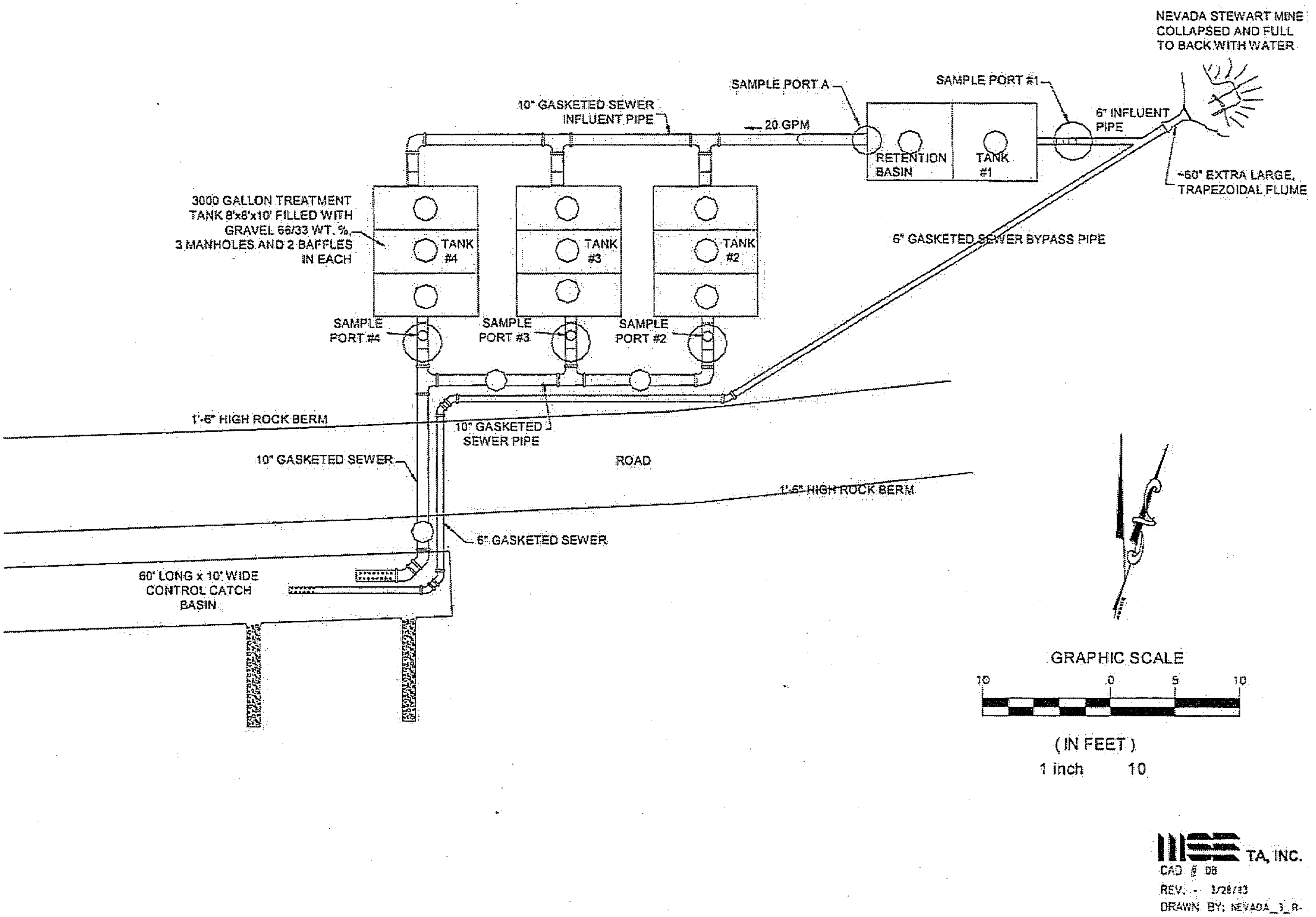
TABLE 6

Treatment Tank Saturation Indices

		OUTFLOW																		
Mineral Phase		**Port 4**	**Port 4**	**Port 4**	**Port 4**	**Port 4**	**Port 4**	**Port 4**	**Port 4**	**Port 4**	**Port 4**	**Port 4**	**Port 4**	**Port 4**	**Port 4**	**Port 4**	**Port 4**	**Port 4**	**Port 4**	**Port 4**
Date		**18-Nov-02**	**19-Mar-03**	**23-Apr-03**	**29-May-03**	**19-Jun-03**	**28-Jul-03**	**19-Aug-03**	**23-Sep-03**	**21-Oct-03**	**25-Nov-03**	**22-Dec-03**	**10-Feb-04**	**9-Mar-04**	**1-Apr-04**	**1-May-04**	**25-May-04**	**22-Jun-04**	**26-Jul-04**	**17-Aug-04**
Charge Balance Error (%)		3.3	-4.1	-2.6	-1.8	2.2	-1.2	-3.2	-4.9	3.3	2.1	-0.5	-0.4	-5.7	-0.3	-4.6	-5.3	-8.8	-5.7	-0.6
pH (s.u.)		6.8	6.9	6.9	6.0	6.1	6.7	6.3	6.7	6.6	6.7	6.5	6.5	6.6	6.2	5.5	6.3	6.8	6.7	6.7
pe		-1.5	2.0	0.7	2.8	2.4	2.8	2.9	2.8	1.7	3.3	3.7	3.8	5.1	5.4	4.6	2.8	0.4	1.5	0.8
Calcite	$CaCO_3$	-0.8	-0.7	-0.7	-1.5	-1.5	-0.8	-1.3	-0.8	-1.0	-0.9	-1.1	-1.2	-1.1	-1.4	-2.2	-1.3	-0.8	-0.8	-0.8
Dolomite	$CaMg(CO_3)_2$	-1.8	-1.7	-1.7	-3.3	-3.3	-1.9	-2.9	-2.0	-2.3	-2.0	-2.6	-2.6	-2.5	-3.2	-4.6	-3.0	-1.9	-1.9	-1.9
Gypsum	$CaSO_4{:}2H_2O$	-1.1	-1.1	-1.2	-1.1	-1.1	-1.1	-1.1	-1.0	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1
Otavite	$CdCO_3$	-9.5	-11.1	-10.7	-9.9	-9.8	-10.7	-10.1	-10.6	-10.4	-9.7	-9.5	-5.5	-5.2	-5.8	-6.0	-7.8	-9.1	-10.1	-10.4
Greenockite	CdS	2.0	1.2	1.4	1.3	1.4	1.3	1.3	1.4	1.3	1.8	1.9	3.4	3.9	3.2	2.5	2.5	2.2	1.5	1.3
Cadmium Hydroxide	$Cd(OH)_2(A)$	-17.8	-19.3	-18.9	-19.1	-18.9	-19.0	-19.0	-19.0	-19.0	-18.1	-18.1	-14.2	-13.8	-14.7	-15.6	-16.6	-17.4	-18.5	-18.8
$CdSO_4$	CdSO4	-20.2	-21.9	-21.6	-19.9	-19.8	-21.3	-20.3	-21.2	-20.9	-20.3	-19.8	-15.9	-15.6	-15.8	-15.3	-17.9	-19.7	-20.7	-21.0
$CdSO_4{:}H_2O$	$CdSO_4{:}H_2O$	-18.4	-20.0	-19.7	-18.1	-18.0	-19.5	-18.4	-19.3	-19.1	-18.5	-18.0	-14.1	-13.7	-14.0	-13.4	-16.1	-17.9	-18.9	-19.2
$Cd_3(PO_4)_2$	$Cd_3(PO_4)_2$	-39.6	-43.8	-42.9	-41.0	-40.6	-42.8	-41.4	-42.6	-42.1	-40.2	-39.6	-27.9	-26.6	-28.1	-30.0	-34.9	-38.7	-41.2	-41.6
Fluorite	CaF_2	-1.4								-1.4										-1.4
Ferrihydrite	$Fe(OH)_3$	-5.4	-2.8	-4.1	-3.8	-3.6	-2.1	-3.0	-2.3	-3.4	-1.1	-1.5	-1.3	**0.1**	-0.5	-3.2	-2.4	-3.2	-2.8	-3.6
Siderite	$FeCO_3$	-2.0	-3.1	-3.1	-3.0	-2.5	-2.9	-2.8	-3.1	-2.7	-2.4	-2.7	-2.6	-2.6	-2.9	-3.2	-2.3	-1.5	-2.1	-2.3
Melanterite	$FeSO_4{:}7H_2O$	-6.3	-7.4	-7.5	-6.6	-6.1	-7.1	-6.6	-7.2	-6.7	-6.5	-6.6	-6.5	-6.5	-6.5	-6.0	-6.0	-5.8	-6.4	-6.6
FeS(ppt)	FeS	**0.2**	**-0.1**	**-0.2**	-1.0	-0.6	**-0.1**	-0.6	**-0.3**	**-0.2**	**-0.1**	-0.6	-3.0	-2.8	-3.2	-4.0	-1.2	**0.4**	**0.3**	**0.1**
Pyrite	FeS_2	14.5	22.1	19.3	20.9	20.6	23.2	22.0	23.2	20.6	23.7	23.7	19.0	22.0	21.7	18.2	20.0	18.3	20.8	19.3
Magnesite	$MgCO_3$	-1.5	-1.5	-1.5	-2.3	-2.3	-1.6	-2.1	-1.6	-1.8	-1.7	-1.9	-2.0	-1.9	-2.2	-3.0	-2.1	-1.5	-1.5	-1.5
Epsomite	$MgSO_4{:}7H_2O$	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.5	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6
Birnessite	MnO_2	-23.7	-16.6	-19.2	-18.6	-19.2	-15.9	-17.6	-15.9	-18.8	-14.5	-14.6	-14.6	-11.8	-12.6	-17.1	-17.6	-20.5	-18.6	-20.0
Rhodochrosite	$MnCO_3$	-1.4	-1.6	-1.5	-2.4	-2.3	-1.8	-2.3	-1.9	-2.0	-1.7	-1.9	-2.0	-2.0	-2.4	-3.0	-2.3	-1.7	-1.8	-1.8
Manganite	MnOOH	-10.7	-7.2	-8.5	-9.1	-9.4	-7.1	-8.5	-7.1	-8.7	-6.2	-6.5	-6.6	-5.1	-5.9	-8.9	-8.4	-9.3	-8.5	-9.2
$Mn_3(PO_4)_2$	$Mn_3(PO_4)_2$	-14.0	-13.9	-13.8	-17.0	-16.6	-14.7	-16.3	-14.8	-15.4	-14.5	-15.2	-15.7	-15.6	-16.4	-19.4	-16.8	-15.3	-14.7	-14.4
$MnHPO_4(C)$	$MnHPO_4$	2.4	2.4	2.4	1.8	1.9	2.3	1.9	2.2	2.1	2.2	2.1	1.9	2.0	1.9	1.1	1.7	1.9	2.3	2.5
Anglesite	$PbSO_4$	-9.4	-11.1	-11.0	-9.5	-9.0	-10.3	-9.8	-10.8	-10.1	-9.6	-9.3	-4.6	-4.7	-4.4	-4.3	-7.4	-9.4	-10.1	-10.1
Cerrusite	$PbCO_3$	-7.4	-9.1	-8.9	-8.2	-7.7	-8.5	-8.4	-9.0	-8.4	-7.8	-7.7	-3.0	-3.0	-3.1	-3.7	-6.0	-7.5	-8.2	-8.3
Galena	PbS	3.8	3.0	3.0	2.7	3.3	3.2	2.8	2.8	3.1	3.5	3.5	5.6	5.8	5.6	4.5	4.1	3.4	3.2	3.2
Hydrocerrusite	$Pb(OH)_2{:}2PbCO_3$	-24.9	-29.7	-29.0	-28.2	-26.4	-28.0	-28.3	-29.5	-28.0	-26.0	-25.9	-12.0	-11.8	-12.4	-15.1	-21.1	-25.2	-27.2	-27.4
Cl-Pyromorphite	$Pb_5(PO_4)_3Cl$	-24.1								-28.1										-26.7
Hydroxypyromorphite	$Pb_5(PO_4)_3OH$	-35.1	-42.1	-41.3	-39.5	-36.5	-39.4	-39.7	-42.0	-39.3	-36.6	-36.2	-13.3	-12.7	-13.0	-18.3	-28.3	-36.1	-38.1	-37.7
$Pb_3(PO_4)_2$	$Pb_3(PO_4)_2$	-20.5	-24.7	-24.2	-22.8	-21.1	-23.0	-23.0	-24.5	-22.9	-21.4	-21.1	-7.3	-7.0	-7.0	-10.1	-16.3	-21.1	-22.2	-21.9
$PbHPO_4$	$PbHPO_4$	-8.2	-9.5	-9.4	-8.5	-8.0	-8.9	-8.7	-9.4	-8.8	-8.4	-8.2	-3.7	-3.5	-3.3	-4.2	-6.5	-8.4	-8.6	-8.4
Hydroxyapatite	$Ca_5(PO_4)_3OH$	4.2	5.6	5.5	**0.1**	**0.4**	4.7	1.7	4.7	3.7	4.1	2.6	2.2	2.8	1.3	-4.5	1.0	3.5	4.7	5.4
Vivianite	$Fe_3(PO_4)2{:}8H_2O$	-3.7	-6.3	-6.5	-6.7	-5.2	-5.8	-5.9	-6.4	-5.3	-4.7	-5.7	-5.6	-5.2	-5.9	-8.1	-4.8	-2.7	-3.7	-3.9
FCO_3 Apatite	$Ca_{9.316}Na_{0.36}Mg_{0.144}(PO_4)_{4.8}(CO_3)_{1.2}F_{2.48}$	16.6								15.9										18.2
Strengite	$FePO_4{:}2H_2O$	-5.4	-2.7	-4.0	-2.5	-2.4	-1.8	-2.0	-2.0	-2.8	-1.0	-1.1	-1.0	0.5	**0.5**	-1.6	-1.8	-3.2	-2.3	-3.0
Amorphous Silica	$SiO_2(am)$	-0.9								-0.9										-0.9
Smithsonite	$ZnCO_3$	-8.4	-10.7	-10.5	-9.7	-9.6	-10.4	-9.9	-10.5	-10.3	-8.2	-7.4	-2.4	-2.7	-2.7	-3.0	-5.6	-8.9	-9.3	-10.0
Sphalerite	ZnS	2.4	0.8	0.9	0.8	0.9	0.8	0.9	0.8	0.8	2.6	3.3	5.8	5.7	5.5	4.8	4.1	1.6	1.7	1.0
Wurtzite	ZnS	**0.3**	-1.2	-1.1	-1.2	-1.1	-1.2	-1.2	-1.2	-1.3	0.5	1.2	3.7	3.6	3.4	2.8	2.0	**-0.4**	**-0.4**	-1.0
Zinc Hydroxide	$Zn(OH)_2(G)$	-10.0	-12.2	-12.0	-12.1	-12.0	-12.1	-12.1	-12.2	-12.1	-9.9	-9.2	-4.2	-4.5	-4.8	-5.9	-7.7	-10.6	-11.1	-11.7
Goslarite	$ZnSO_4{:}7H_2O$	-12.7	-15.0	-14.9	-13.2	-13.1	-14.6	-13.6	-14.6	-14.3	-12.4	-11.3	-6.3	-6.6	-6.3	-5.8	-9.2	-13.1	-13.5	-14.2
$Zn_3(PO_4)_2{:}4H_2O$	$Zn_3(PO_4)_2{:}4H_2O$	-25.2	-31.6	-31.0	-29.1	-28.8	-30.9	-29.5	-31.2	-30.5	-24.6	-22.1	-7.3	-8.0	-7.8	-9.8	-16.9	-27.1	-27.6	-29.1
Jarosite-K	$KFe_3(SO_4)_2(OH)_6$	-19.0								-12.2										-13.2
Jarosite-Na	$NaFe_3(SO_4)_2(OH)_6$	-21.4								-14.6										-15.6
Jarosite-H	$(H_3O)Fe_3(SO_4)_2(OH)_6$	-24.6	-17.2	-21.1	-16.5	-16.0	-14.2	-14.7	-14.7	-17.5	-11.5	-11.5	-11.1	-7.0	-7.5	-12.4	-13.4	-17.4	-15.9	-18.5
Amorphous Aluminum Hydroxide	$Al(OH)_3(am)$	-1.6								-1.6										-1.4
Aluminum Sulphate	$Al_4(OH)_{10}SO_4$	**0.4**								0.9										0.5
Aluminum Sulphate	AlOHSO4	-3.4								-2.8										-3.1
Gibbsite	$Al(OH)_3$	**0.2**								**0.2**										**0.3**
Boehmite	AlOOH	**0.2**								**0.2**										**0.3**
Millerite	NiS	3.1								3.5										3.5
Nickel Hydroxide	$Ni(OH)_2$	-3.3								-3.5										-3.5

Note: Bolded and shaded values indicate near-saturation conditions (SI of -0.5 to 0.5).

FIGURES



Source: MSE Technology Applications, 2003

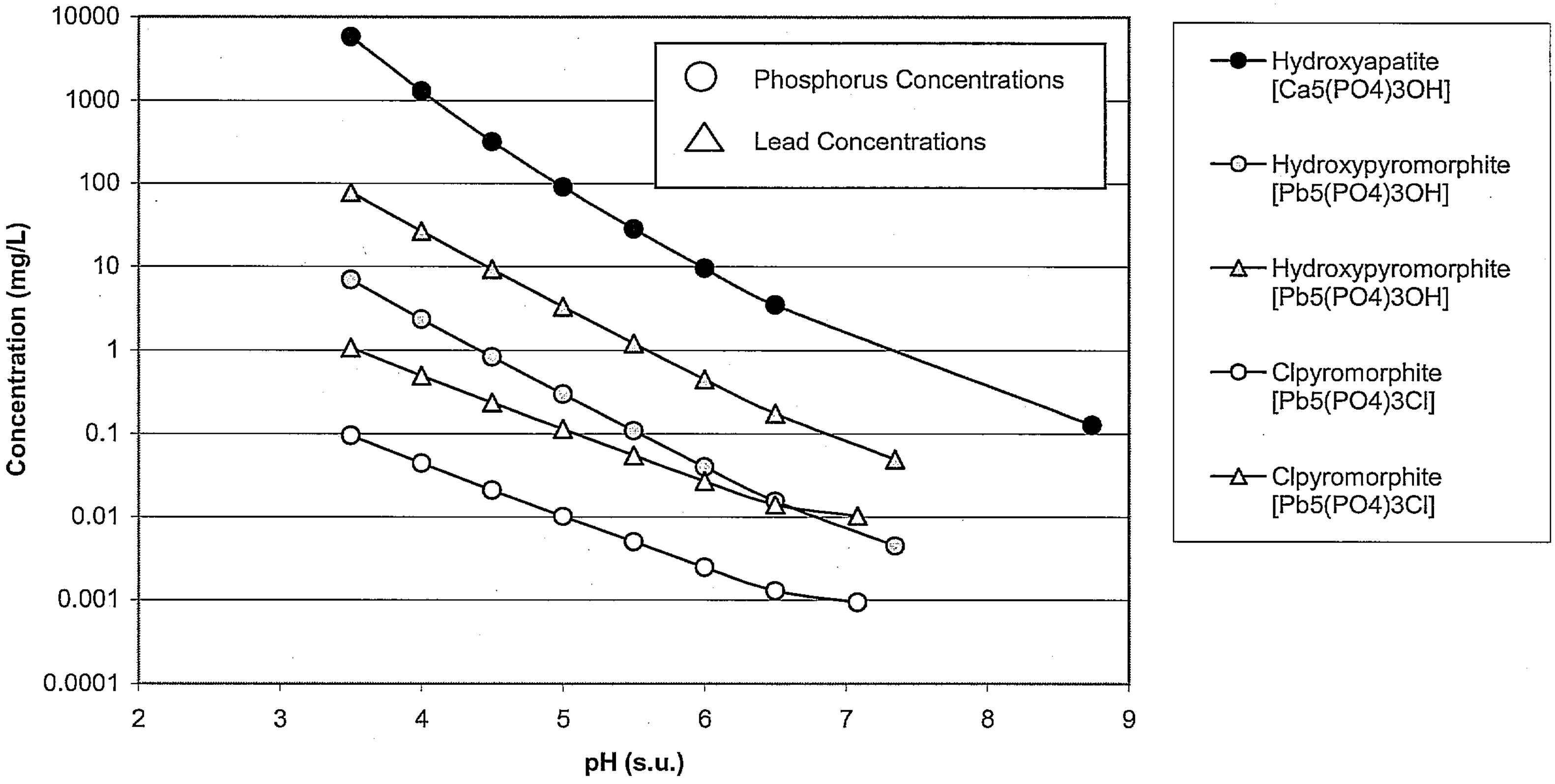
FIGURE 1

NEVADA STEWART MINE TREATMENT SYSTEM DESIGN

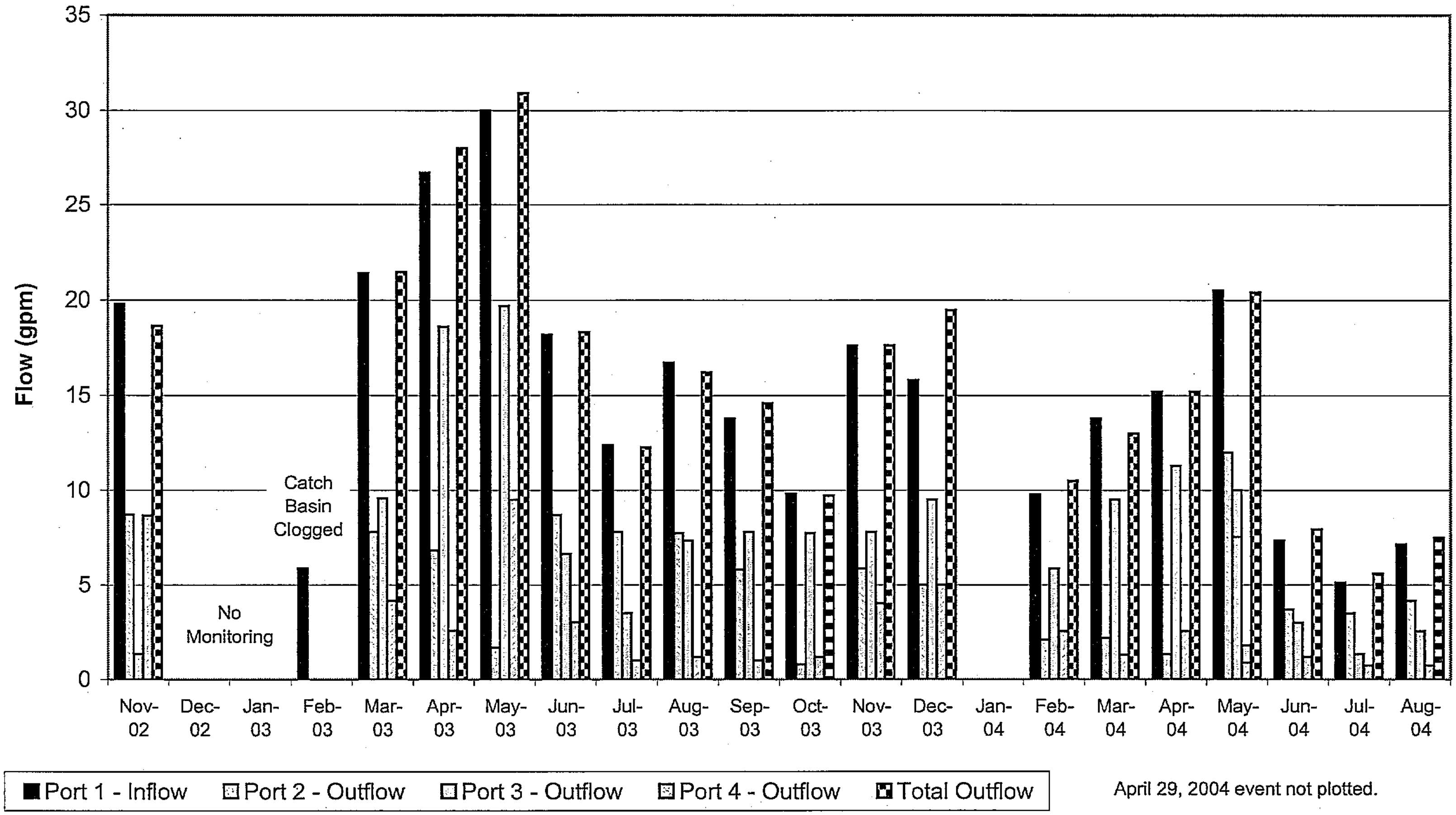
MSE/INTERSTATE MONITORING/ID

DRAWING NO. 0231166700fg01.fh11 DATE 07/10/03 DRAWN BY EFS

Golder Associates



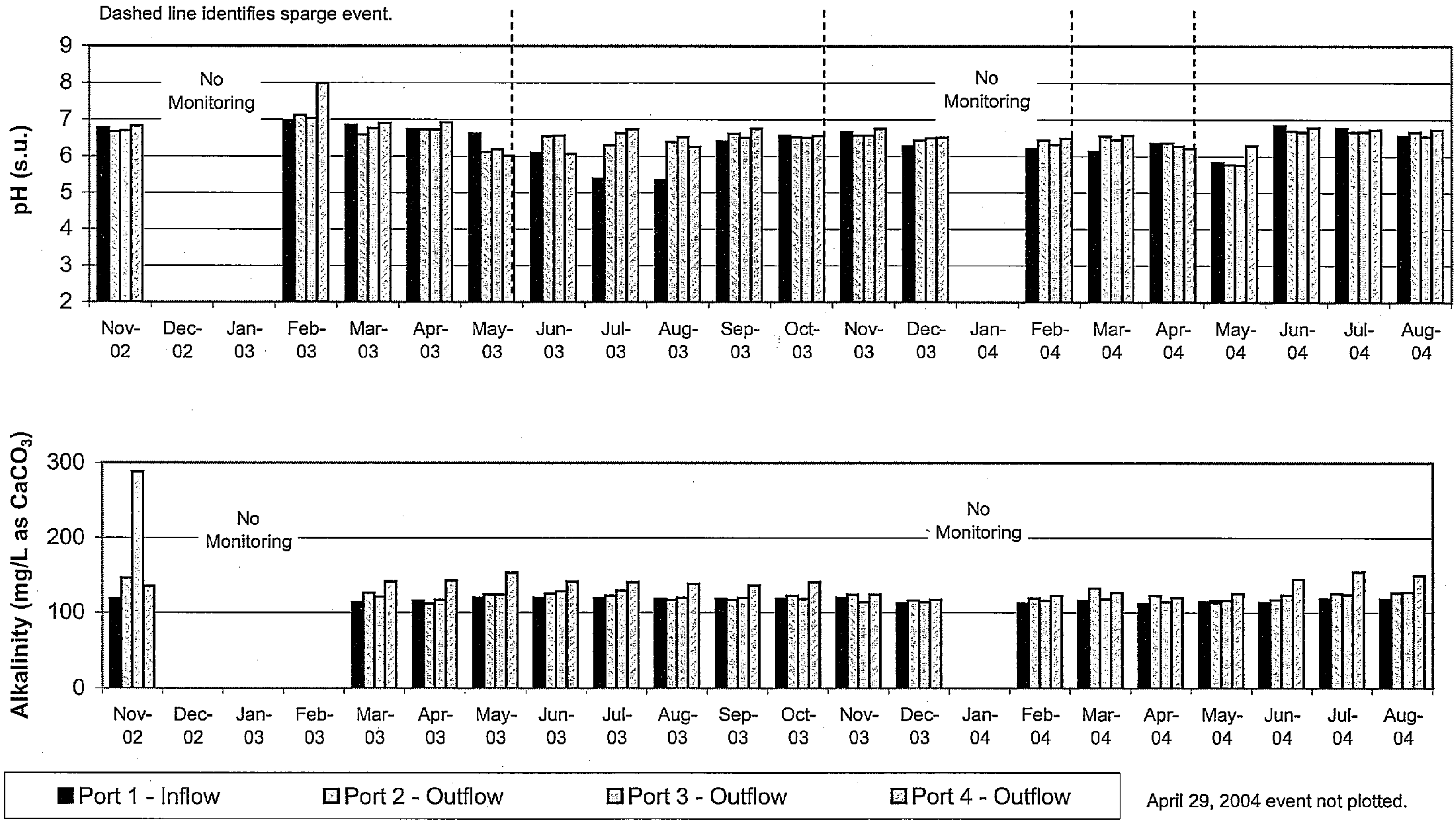
Golder Associates	TITLE **Phosphate Mineral Solubility**				
MSE **Nevada Stewart Mine**	DRAWN	CR	DATE	November 2004	JOB NO. 023-1166
	CHECKED	RV	SCALE	na	DWG. NO.
	REVIEWED	RV	FILE NO.	MSE Data - Nov 2004.xls	FIGURE NO. **2**



April 29, 2004 event not plotted.

Golder Associates

	TITLE	**Treatment Tank Flows**					
MSE **Nevada Stewart Mine**	DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
	CHECKED	RV	SCALE	na	DWG. NO.	
	REVIEWED	RV	FILE NO.	MSE Data - Nov 2004.xls	FIGURE NO.	**3**



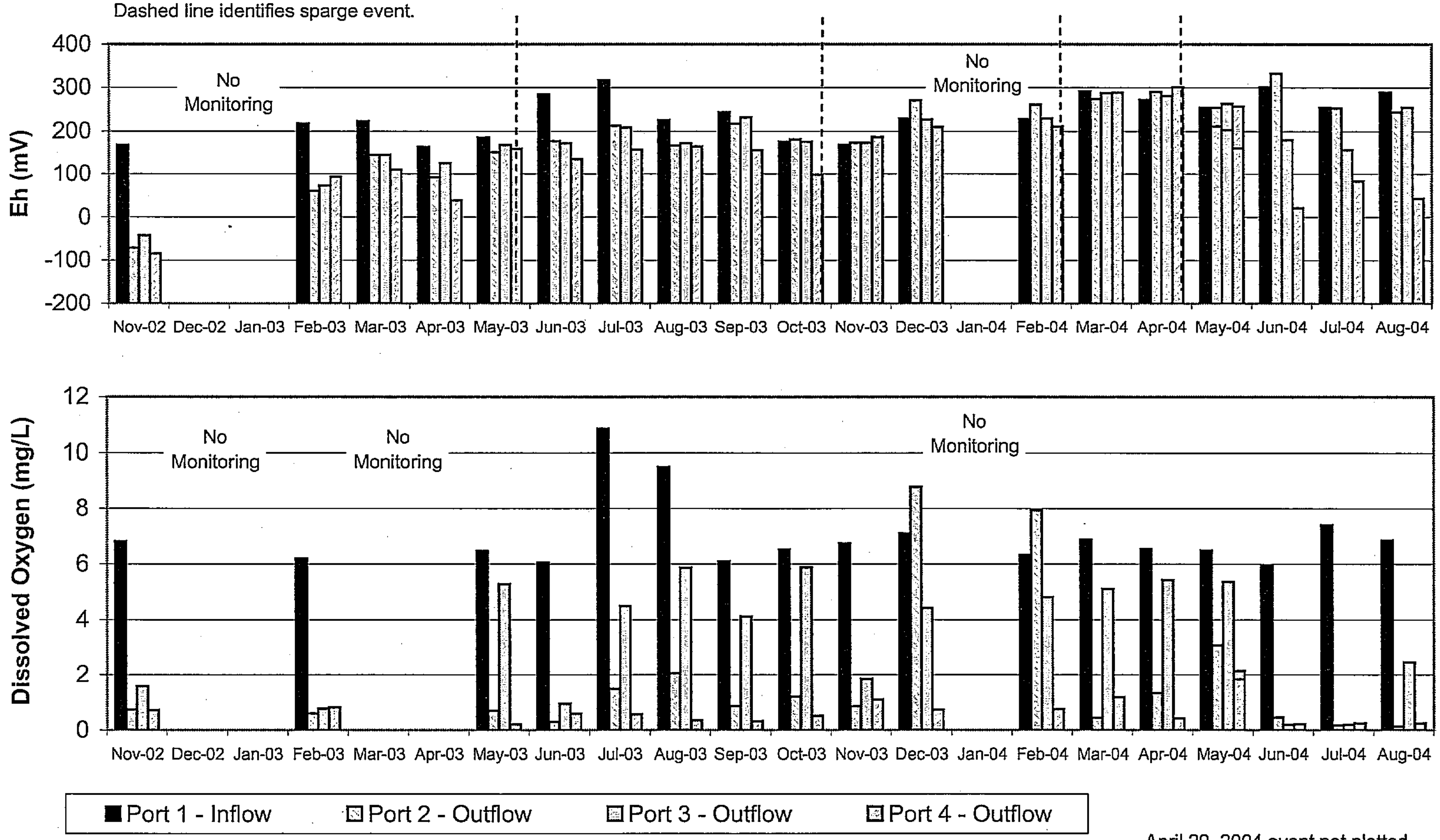
Dashed line identifies sparge event.

April 29, 2004 event not plotted.

Golder Associates

	TITLE **Treatment Tank Alkalinity and pH**		
MSE **Nevada Stewart Mine**	DRAWN CR	DATE November 2004	JOB NO. 023-1166
	CHECKED RV	SCALE na	DWG. NO.
	REVIEWED RV	FILE NO. MSE Data - Nov 2004.xls	FIGURE NO. 4

Dashed line identifies sparge event.



April 29, 2004 event not plotted.

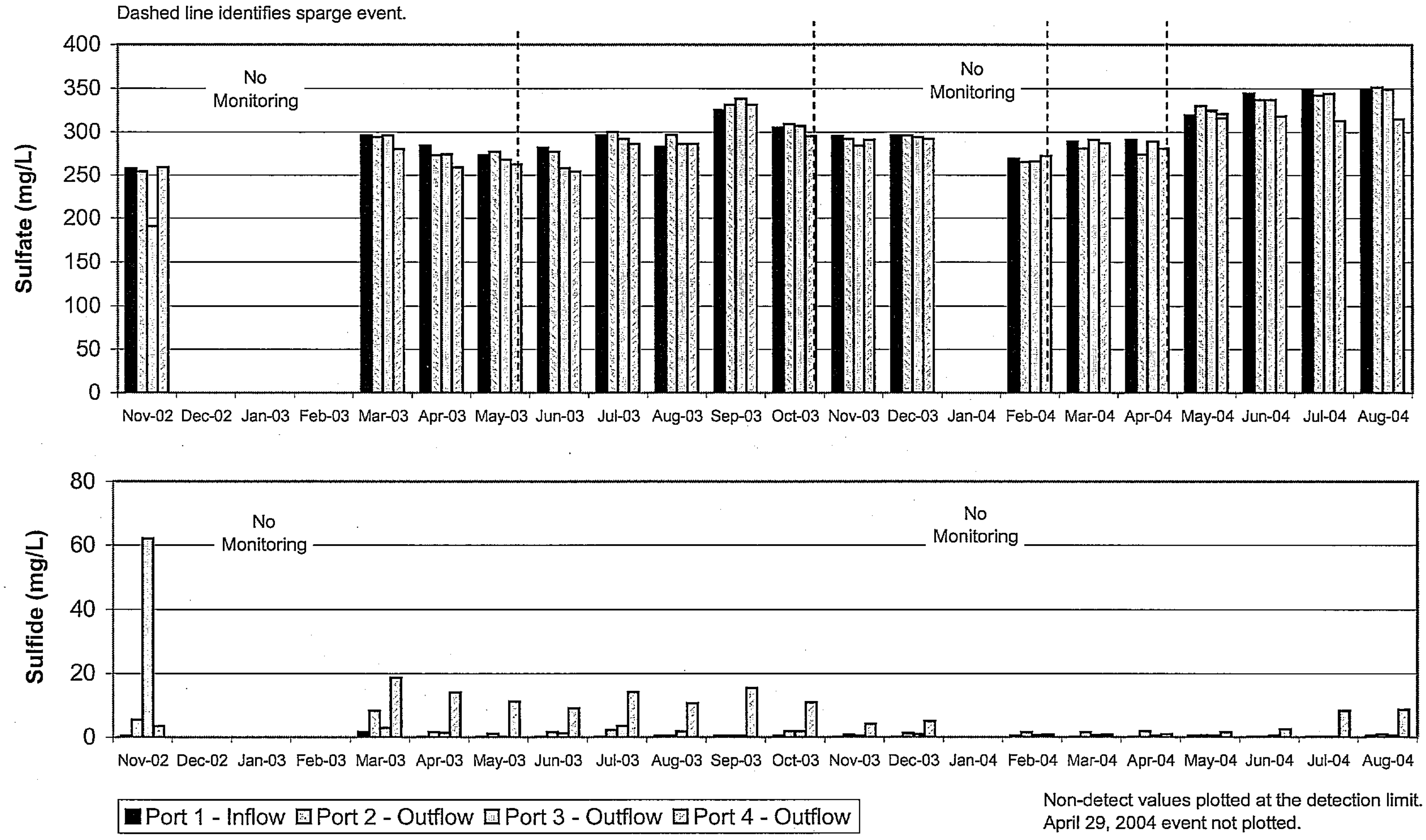
Golder Associates

MSE
Nevada Stewart Mine

TITLE

Treatment Tank Eh and Dissolved Oxygen

DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	MSE Data - Nov 2004.xls	FIGURE NO.	5

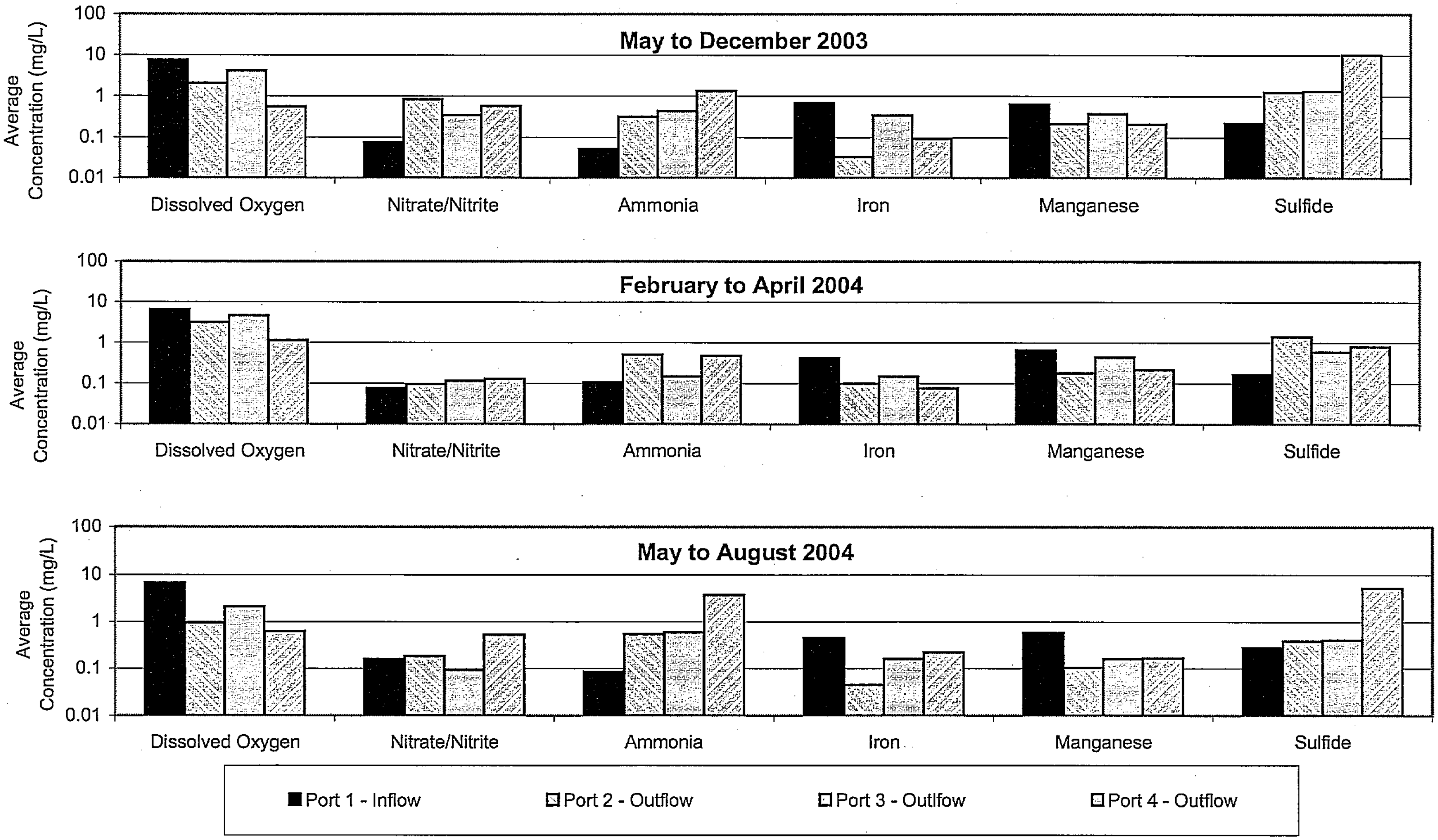


Non-detect values plotted at the detection limit.
April 29, 2004 event not plotted.

Golder Associates

MSE
Nevada Stewart Mine

TITLE	**Treatment Tank Sulfate and Sulfide**				
DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	MSE Data - Nov 2004.xls	FIGURE NO.	6



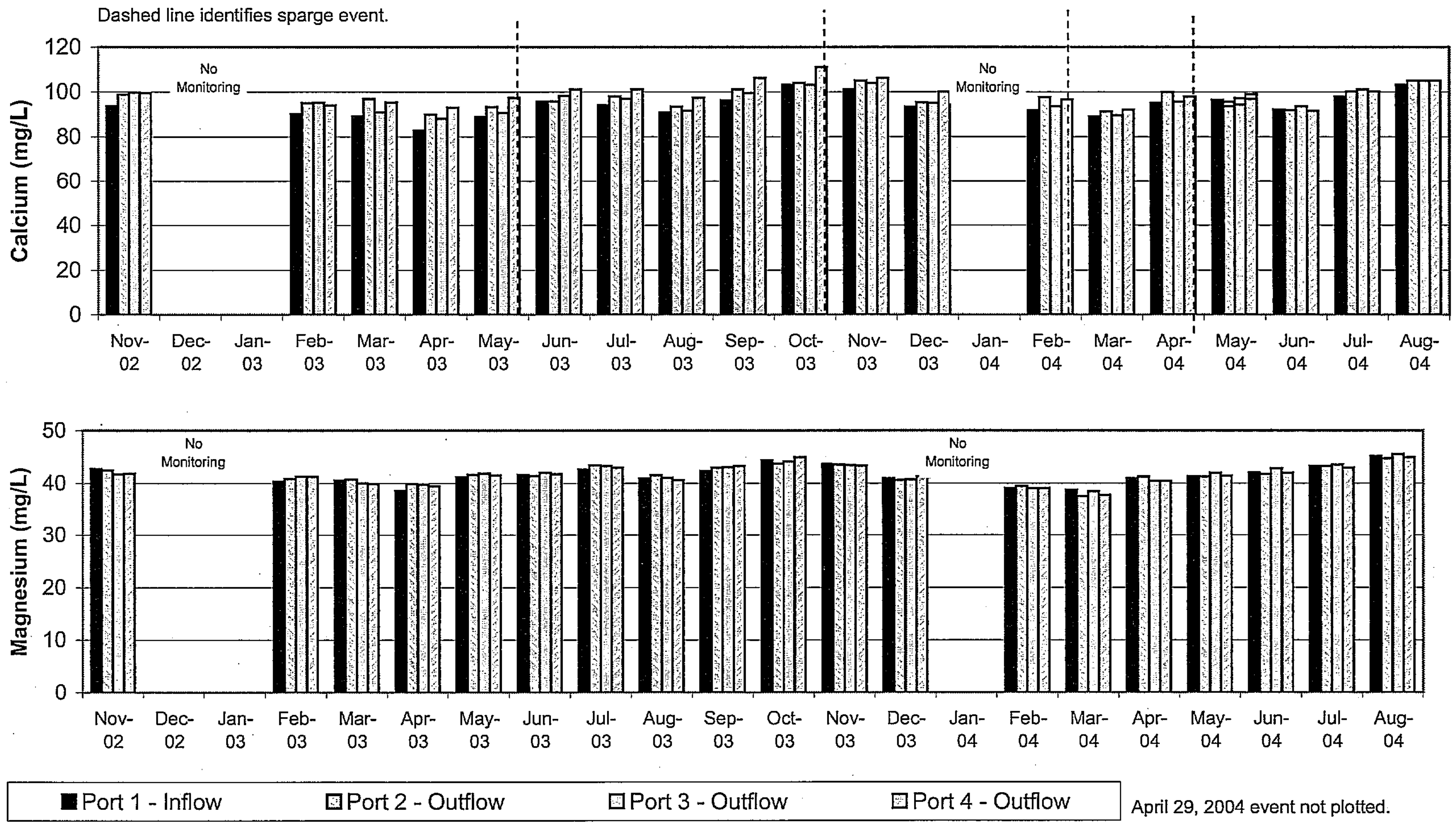
Golder Associates

TITLE

Treatment Tank Redox Constituents - Average Concentrations in 2003 and 2004

Terragraphics
Success Mine and Mill Site

DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	MSE Data - Nov 2004.xls	FIGURE NO.	7



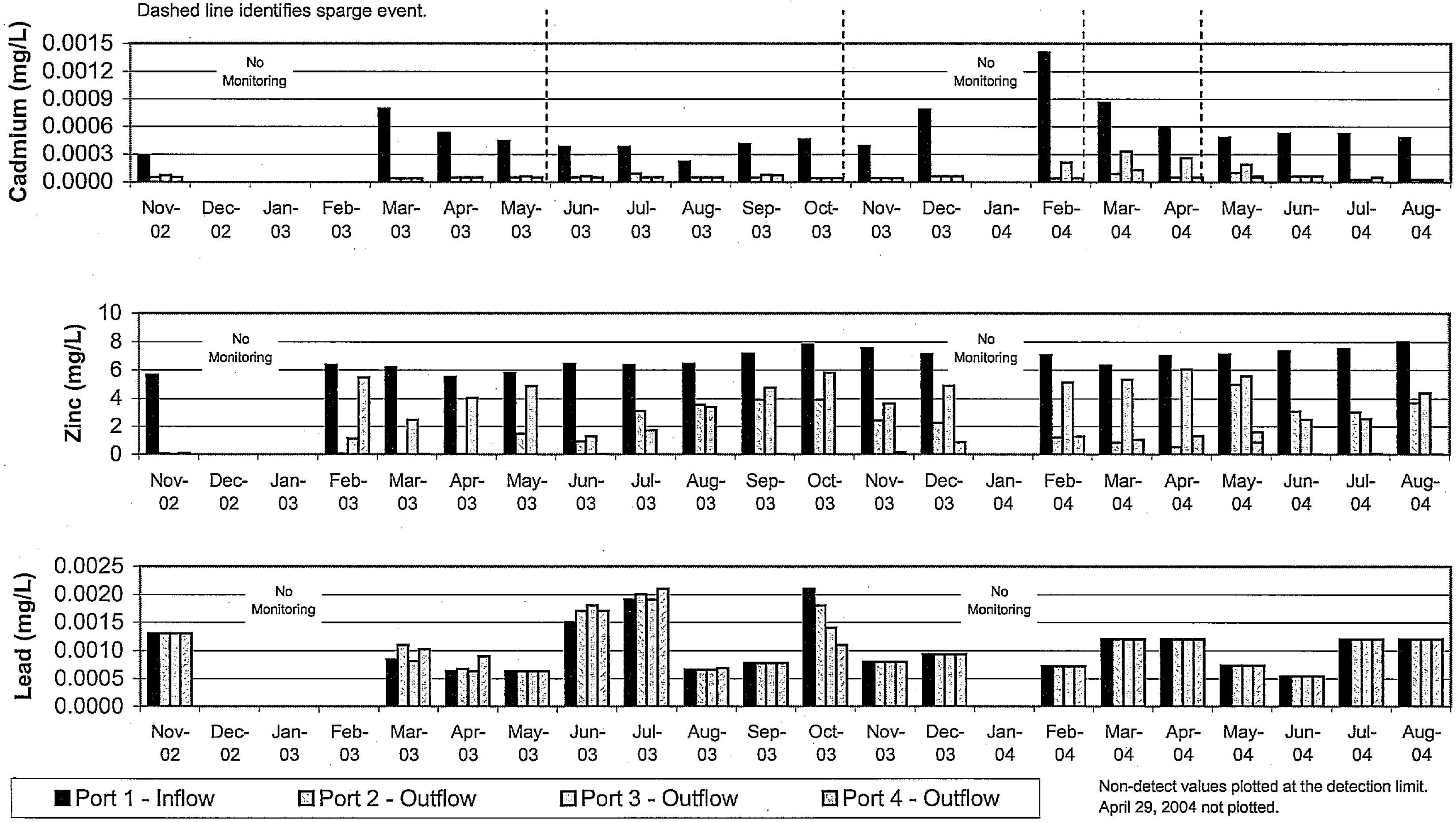
Dashed line identifies sparge event.

April 29, 2004 event not plotted.

Golder Associates

	TITLE					
	Treatment Tank Dissolved Calcium and Magnesium					
MSE **Nevada Stewart Mine**	DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
	CHECKED	RV	SCALE	na	DWG. NO.	
	REVIEWED	RV	FILE NO.	MSE Data - Nov 2004.xls	FIGURE NO.	8

Dashed line identifies sparge event.



Non-detect values plotted at the detection limit.
April 29, 2004 not plotted.

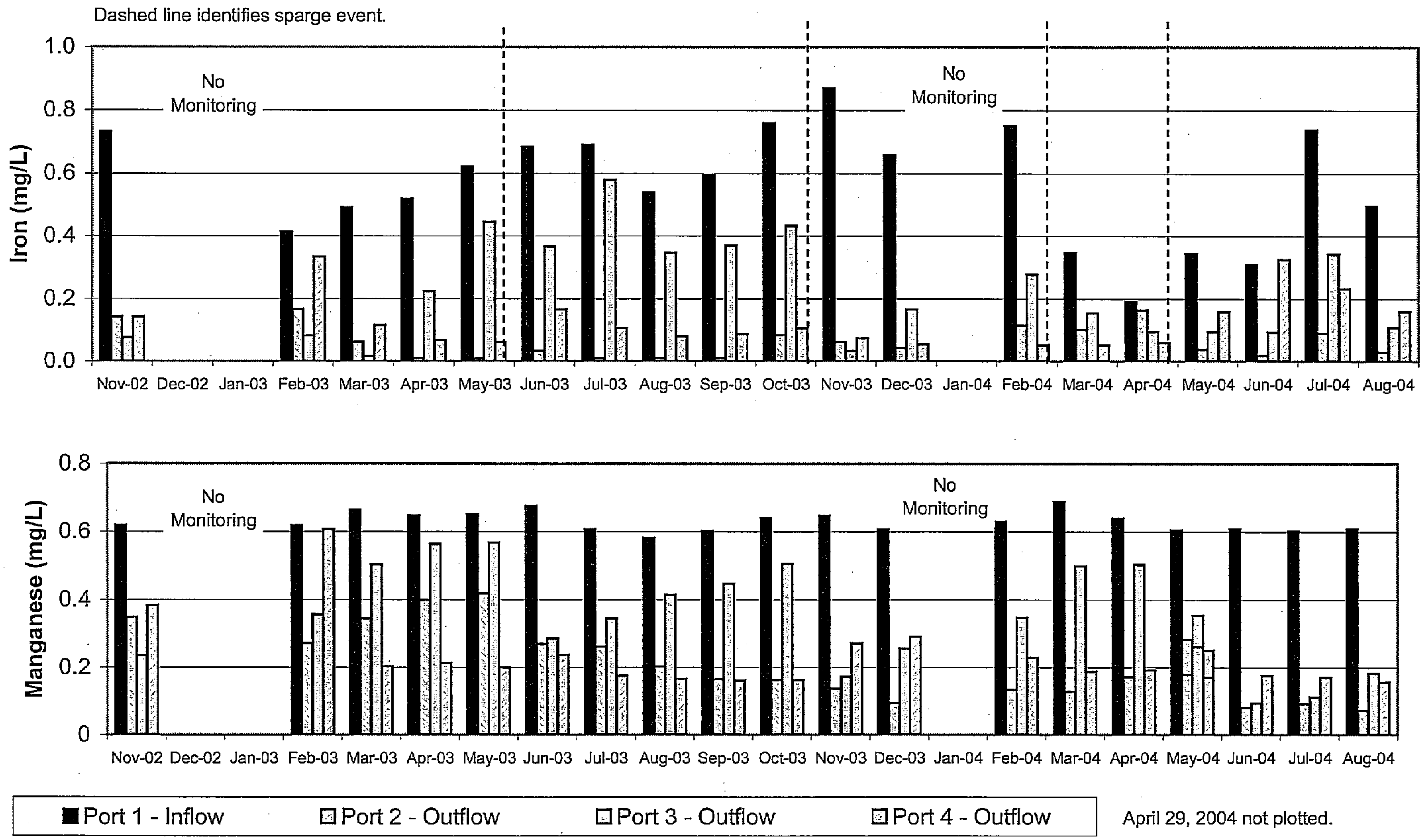
Golder Associates

MSE
Nevada Stewart Mine

TITLE

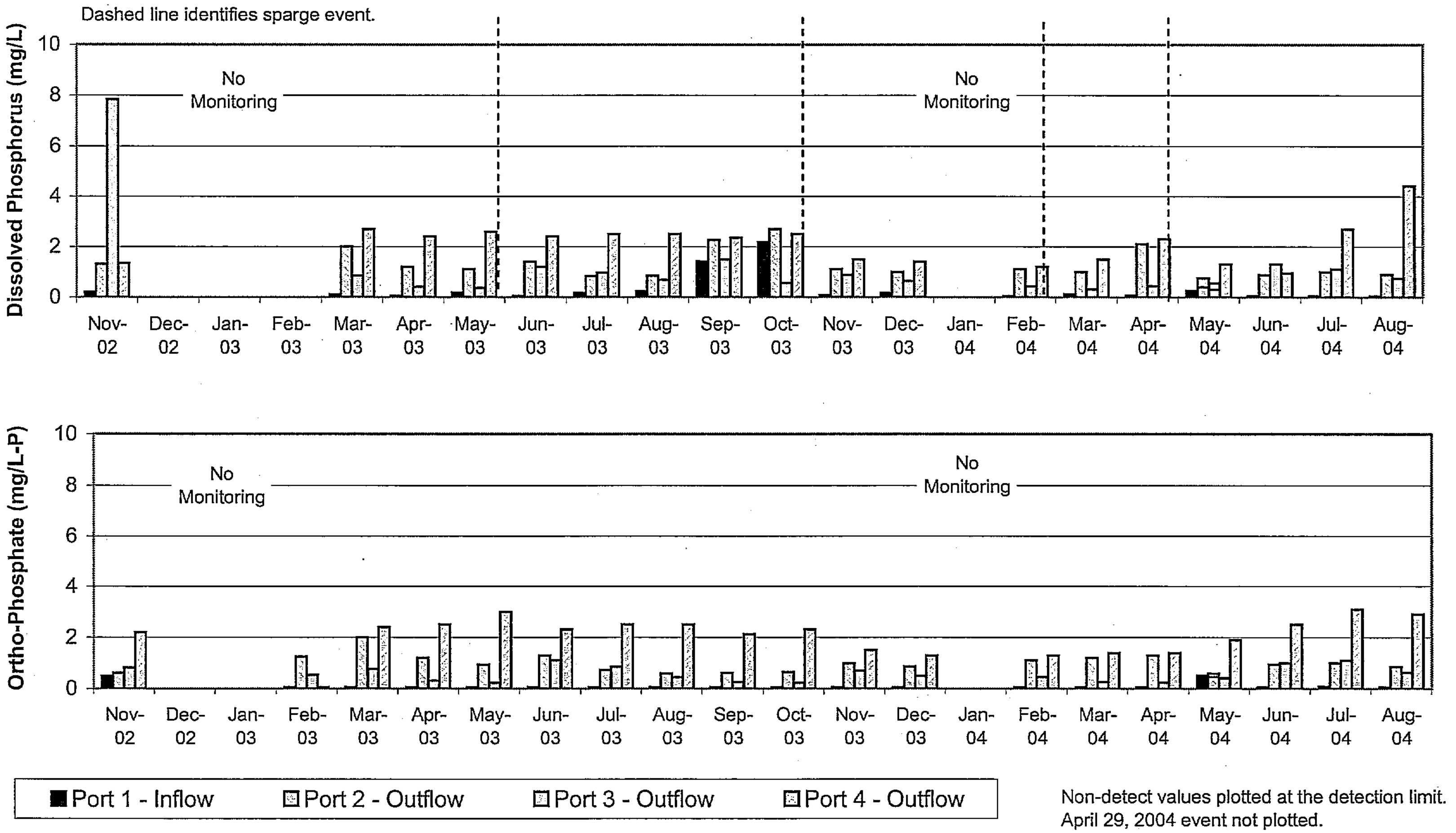
Treatment Tank Dissolved Cadmium, Lead and Zinc

DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	MSE Data - Nov 2004.xls	FIGURE NO.	9



April 29, 2004 not plotted.

Golder Associates	TITLE **Treatment Tank Dissolved Iron and Manganese**		
MSE **Nevada Stewart Mine**	DRAWN CR	DATE November 2004	JOB NO. 023-1166
	CHECKED RV	SCALE na	DWG. NO.
	REVIEWED RV	FILE NO. MSE Data - Nov 2004.xls	FIGURE NO. 10

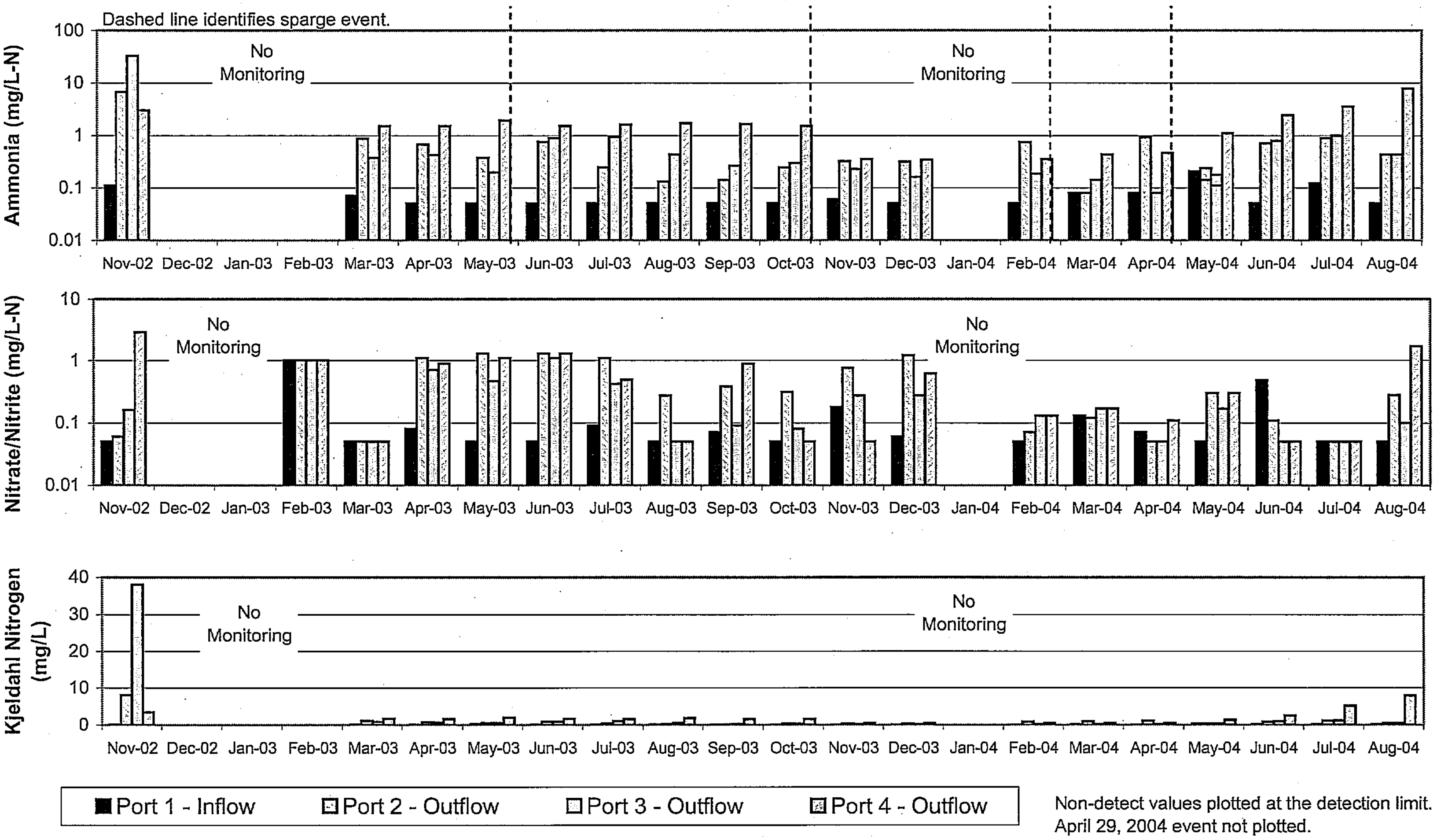


Non-detect values plotted at the detection limit.
April 29, 2004 event not plotted.

Golder Associates

MSE
Nevada Stewart Mine

TITLE	**Treatment Tank Dissolved Phosphorus and Ortho-Phosphate**				
DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	MSE Data - Nov 2004.xls	FIGURE NO.	11

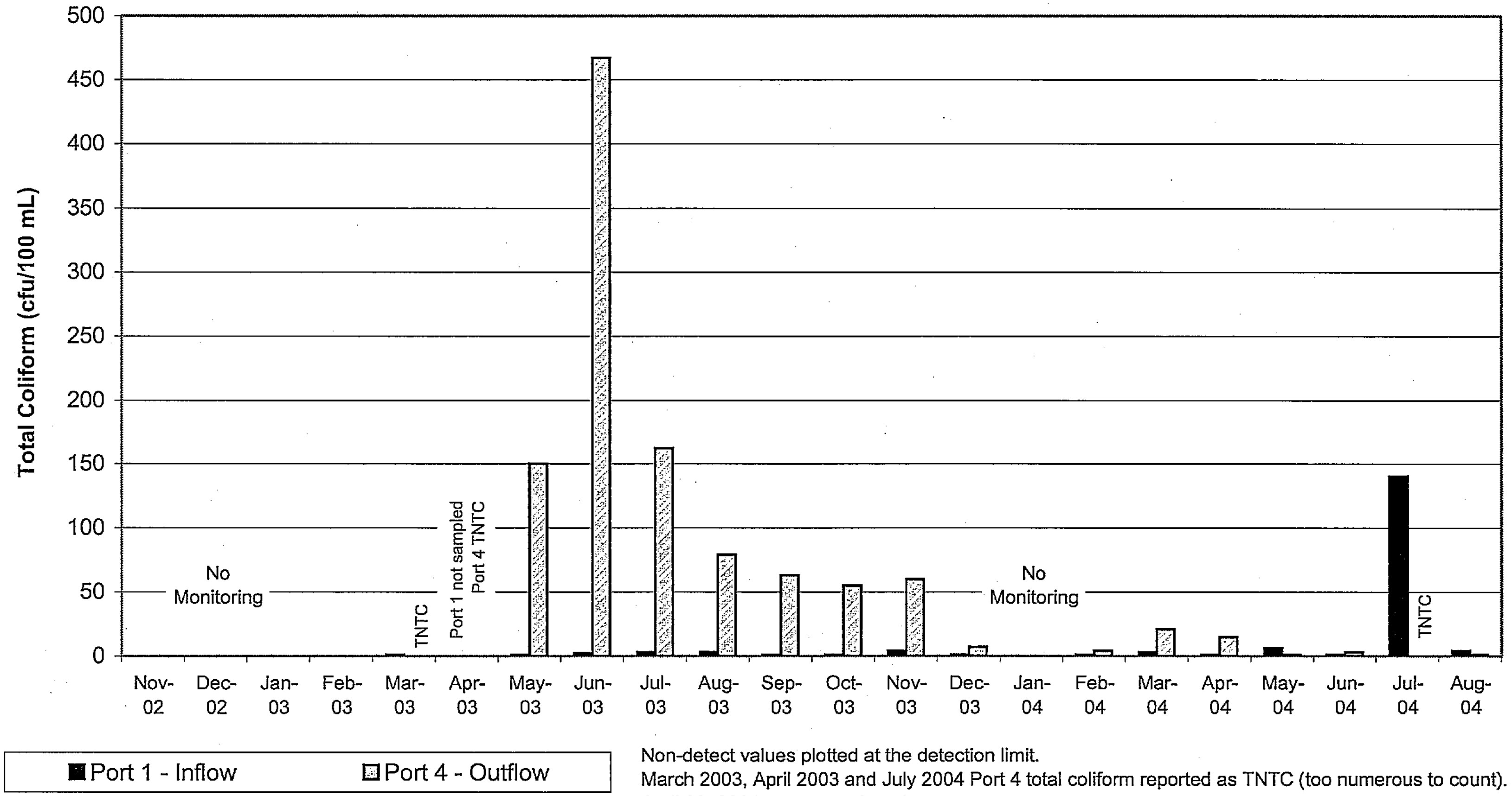


Non-detect values plotted at the detection limit.
April 29, 2004 event not plotted.

Golder Associates

TITLE	**Treatment Tank Ammonia, Nitrate/Nitrite and Kjeldahl Nitrogen**				
DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	MSE Data - Nov 2004.xls	FIGURE NO.	12

MSE
Nevada Stewart Mine



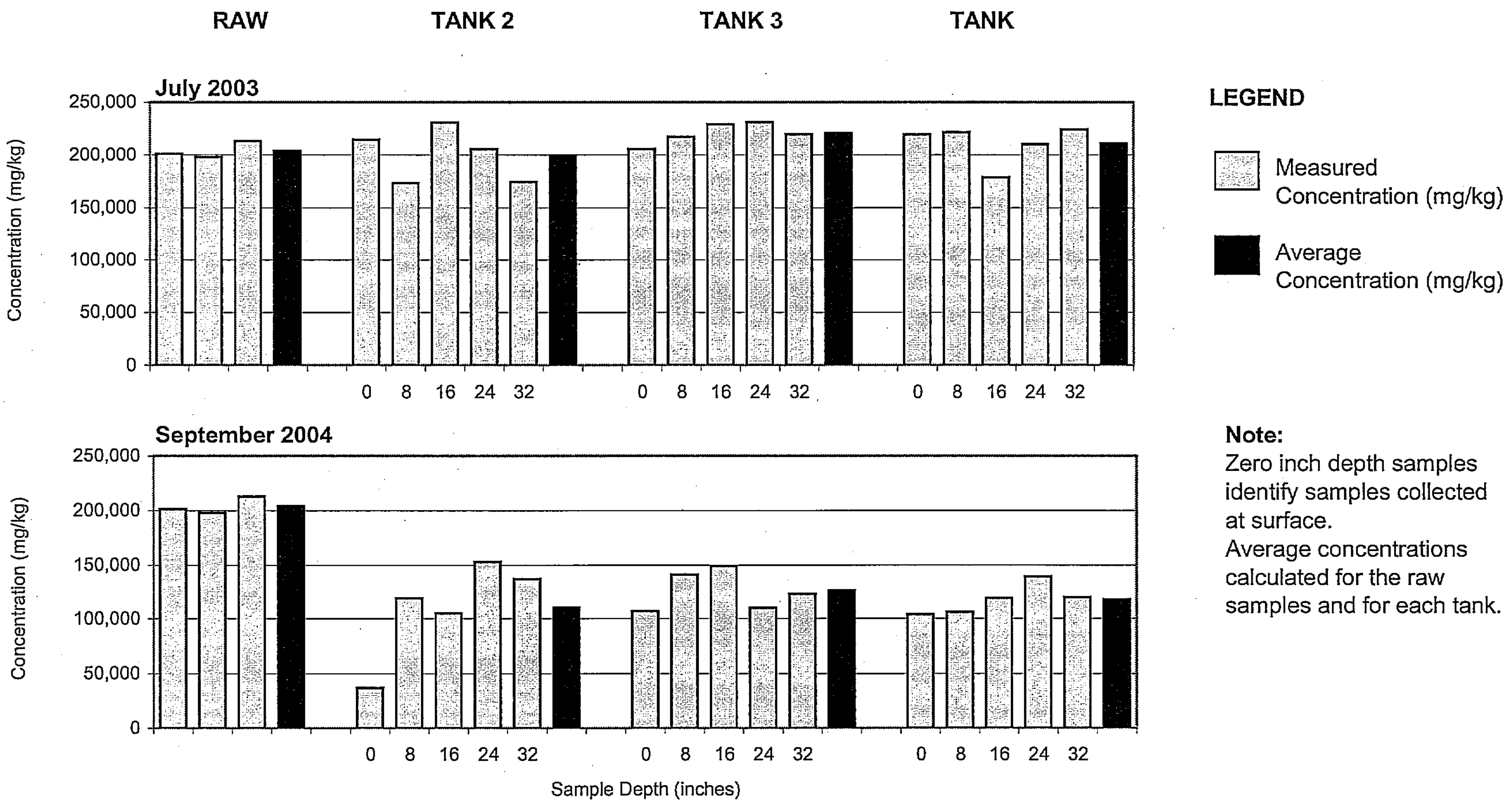
Non-detect values plotted at the detection limit.
March 2003, April 2003 and July 2004 Port 4 total coliform reported as TNTC (too numerous to count).
April 29, 2004 event not plotted.

Golder Associates

MSE
Nevada Stewart Mine

TITLE
Treatment Tank Total Coliform

DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	MSE Data - Nov 2004.xls	FIGURE NO.	13

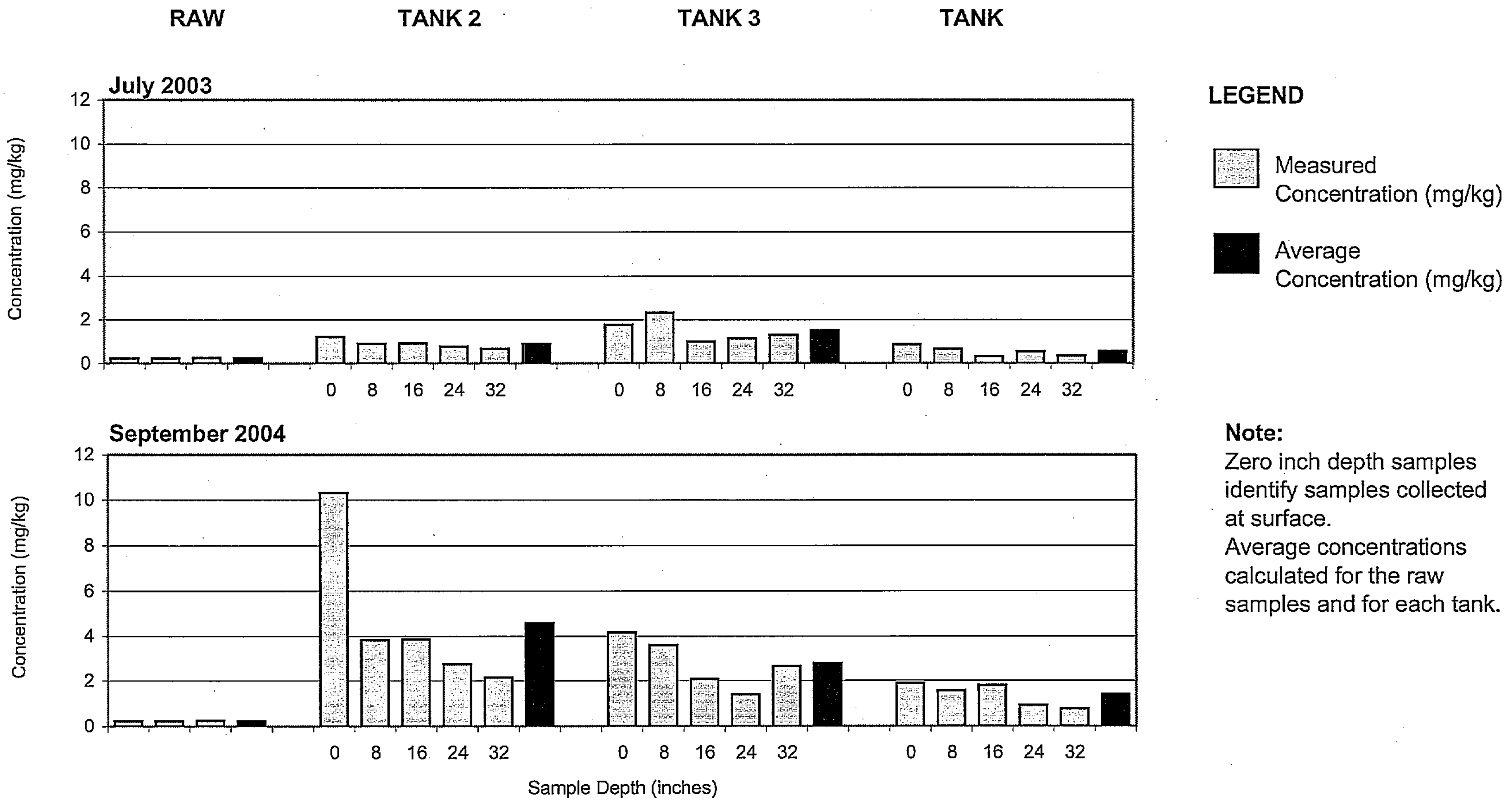


Note:
Zero inch depth samples identify samples collected at surface.
Average concentrations calculated for the raw samples and for each tank.

Golder Associates

MSE
Nevada Stewart Mine

TITLE	**Solid Phase Concentrations - Calcium**				
DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Fishbone Digest Data - Nov 04.xls	FIGURE NO.	14



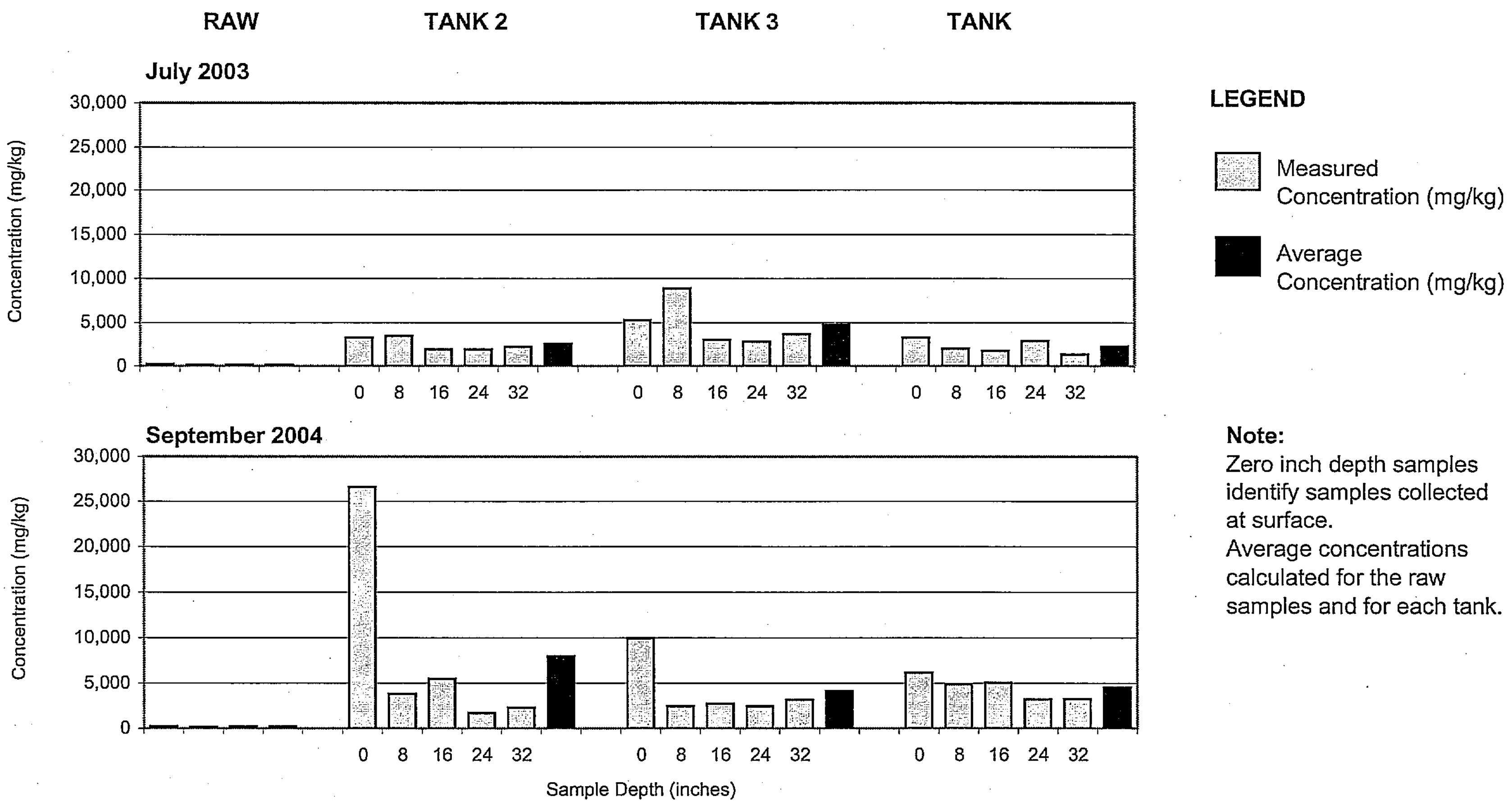
Note:
Zero inch depth samples identify samples collected at surface.
Average concentrations calculated for the raw samples and for each tank.

Golder Associates

MSE
Nevada Stewart Mine

TITLE
Solid Phase Concentrations - Cadmium

DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Fishbone Digest Data - Nov 04.xls	FIGURE NO.	15



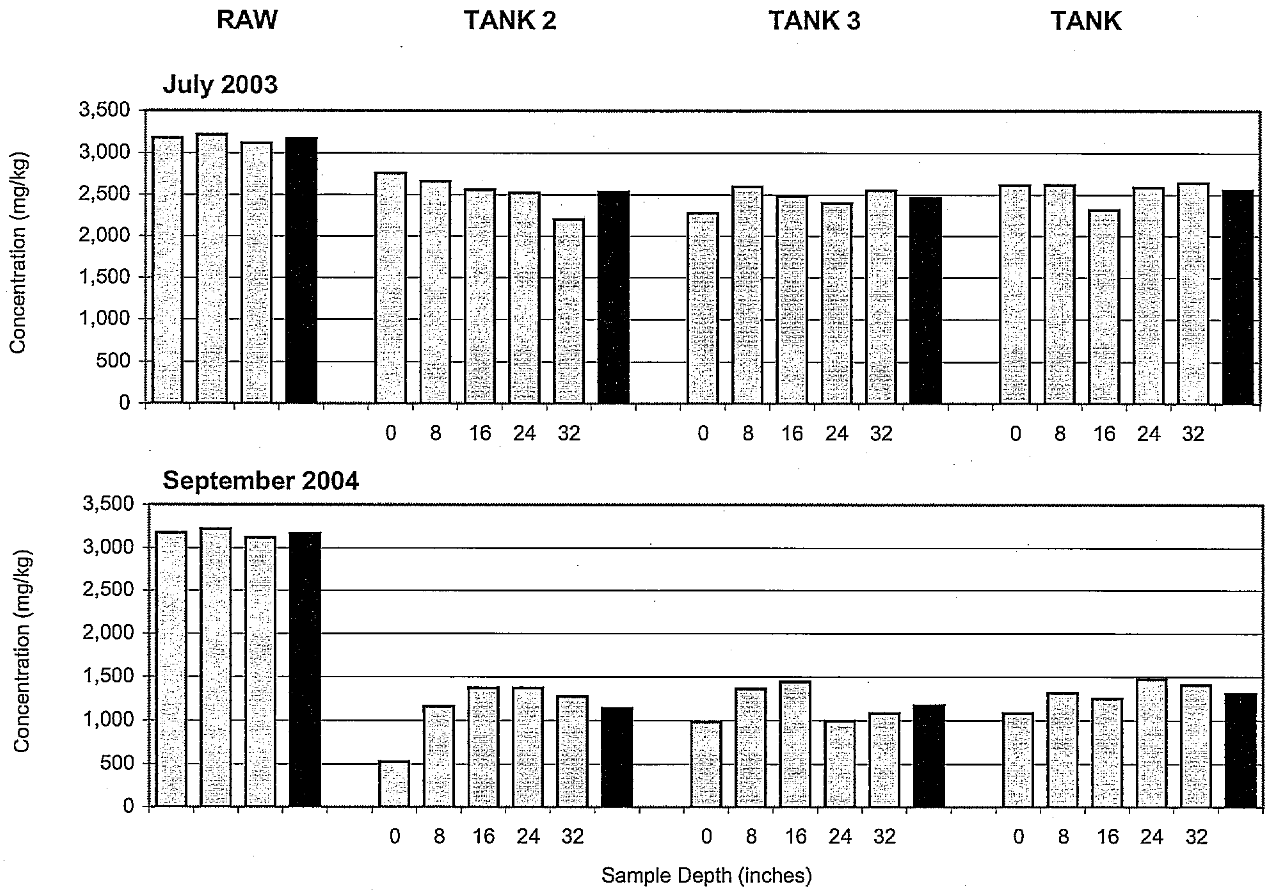
Note:
Zero inch depth samples identify samples collected at surface.
Average concentrations calculated for the raw samples and for each tank.

Golder Associates

TITLE
Solid Phase Concentrations - Iron

MSE
Nevada Stewart Mine

DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Fishbone Digest Data - Nov 04.xls	FIGURE NO.	16



LEGEND

▨ Measured Concentration (mg/kg)

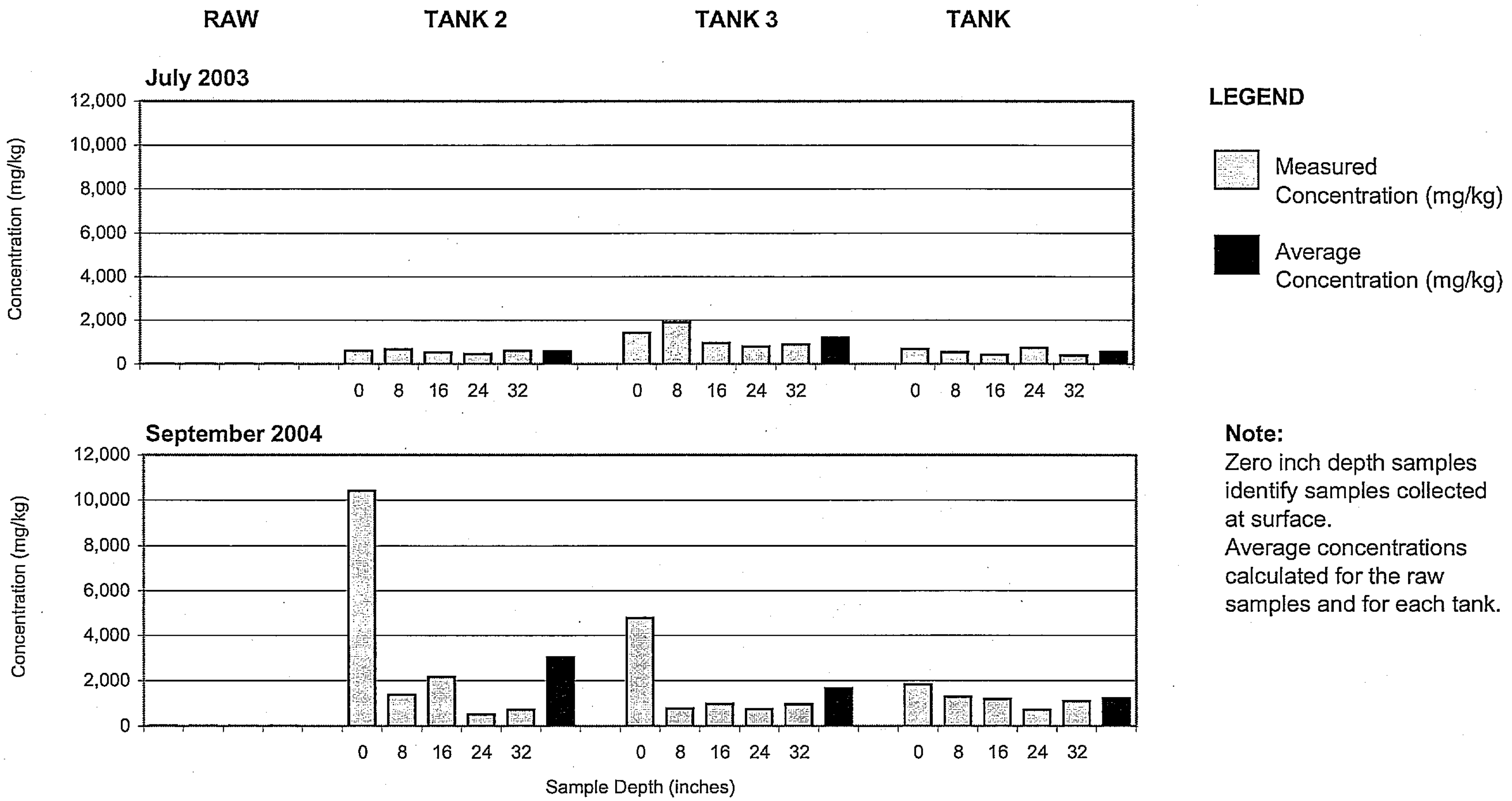
■ Average Concentration (mg/kg)

Note:
Zero inch depth samples identify samples collected at surface.
Average concentrations calculated for the raw samples and for each tank.

Golder Associates

TITLE					
Solid Phase Concentrations - Magnesium					
DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Fishbone Digest Data - Nov 04.xls	FIGURE NO.	17

MSE
Nevada Stewart Mine



Note:
Zero inch depth samples identify samples collected at surface.
Average concentrations calculated for the raw samples and for each tank.

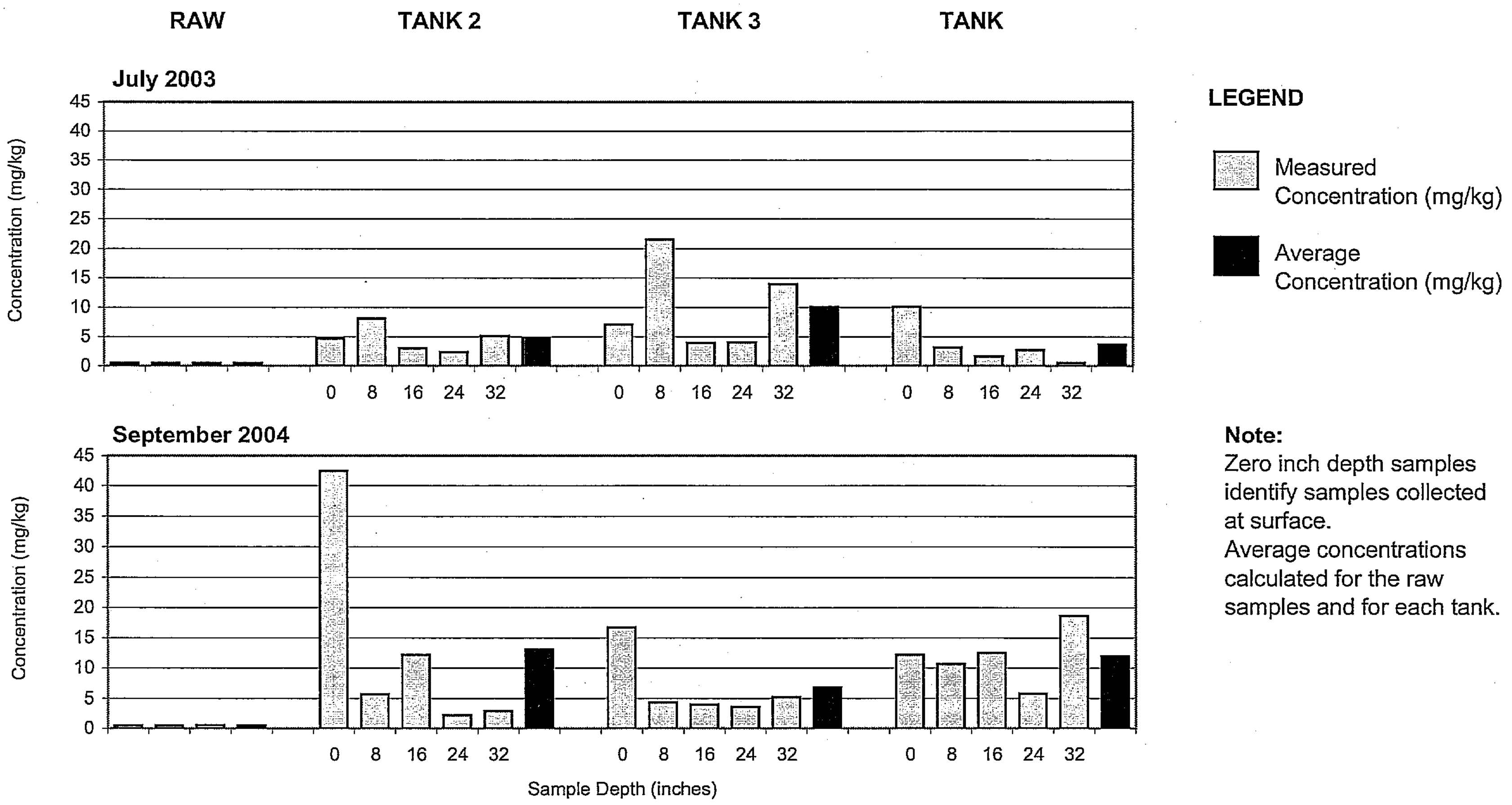
Golder Associates

TITLE

Solid Phase Concentrations - Manganese

DRAWN CR	DATE November 2004	JOB NO. 023-1166	
CHECKED RV	SCALE na	DWG. NO.	
REVIEWED RV	FILE NO. Fishbone Digest Data - Nov 04.xls	FIGURE NO. 18	

MSE
Nevada Stewart Mine



Note:
Zero inch depth samples identify samples collected at surface.
Average concentrations calculated for the raw samples and for each tank.

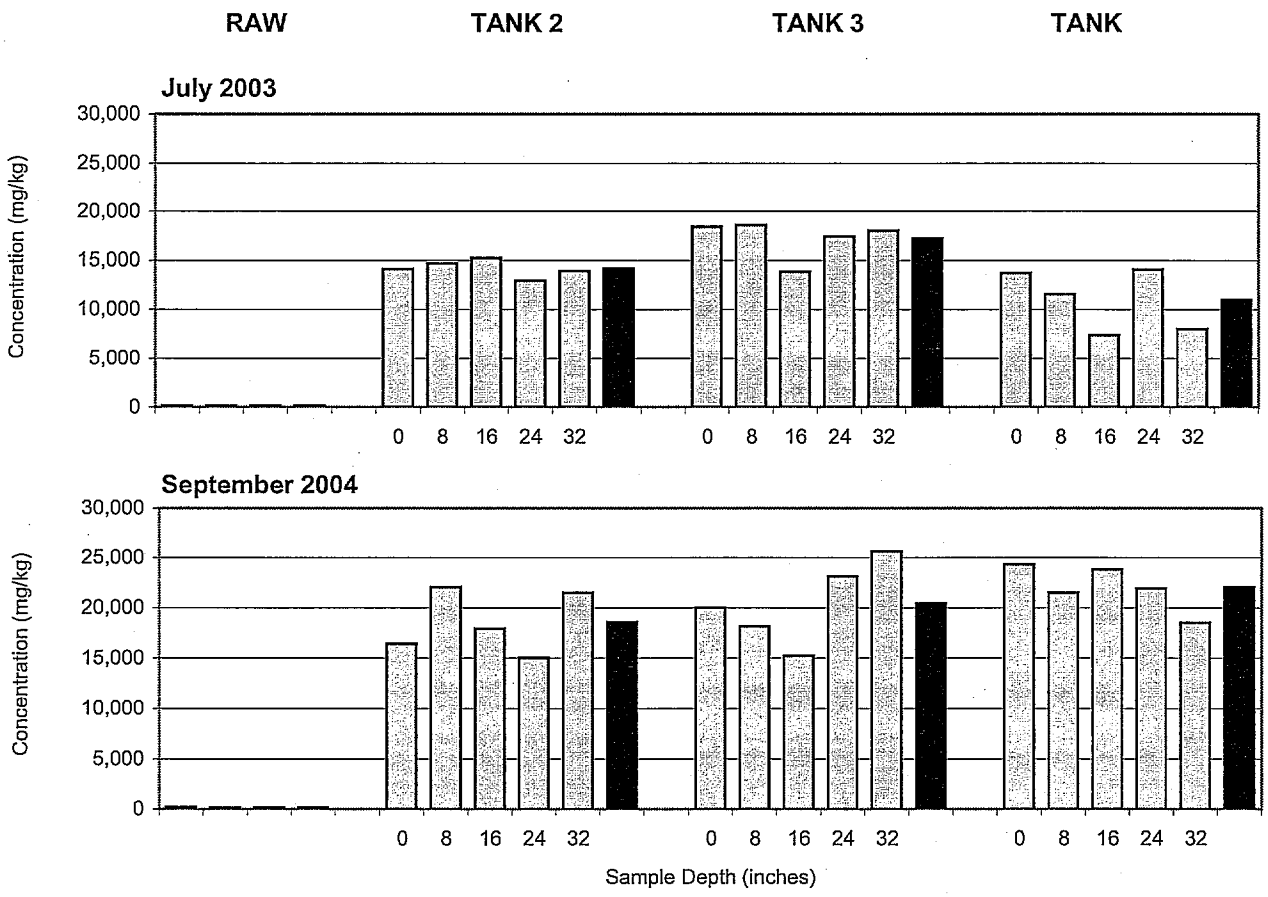
Golder Associates

TITLE

Solid Phase Concentrations - Lead

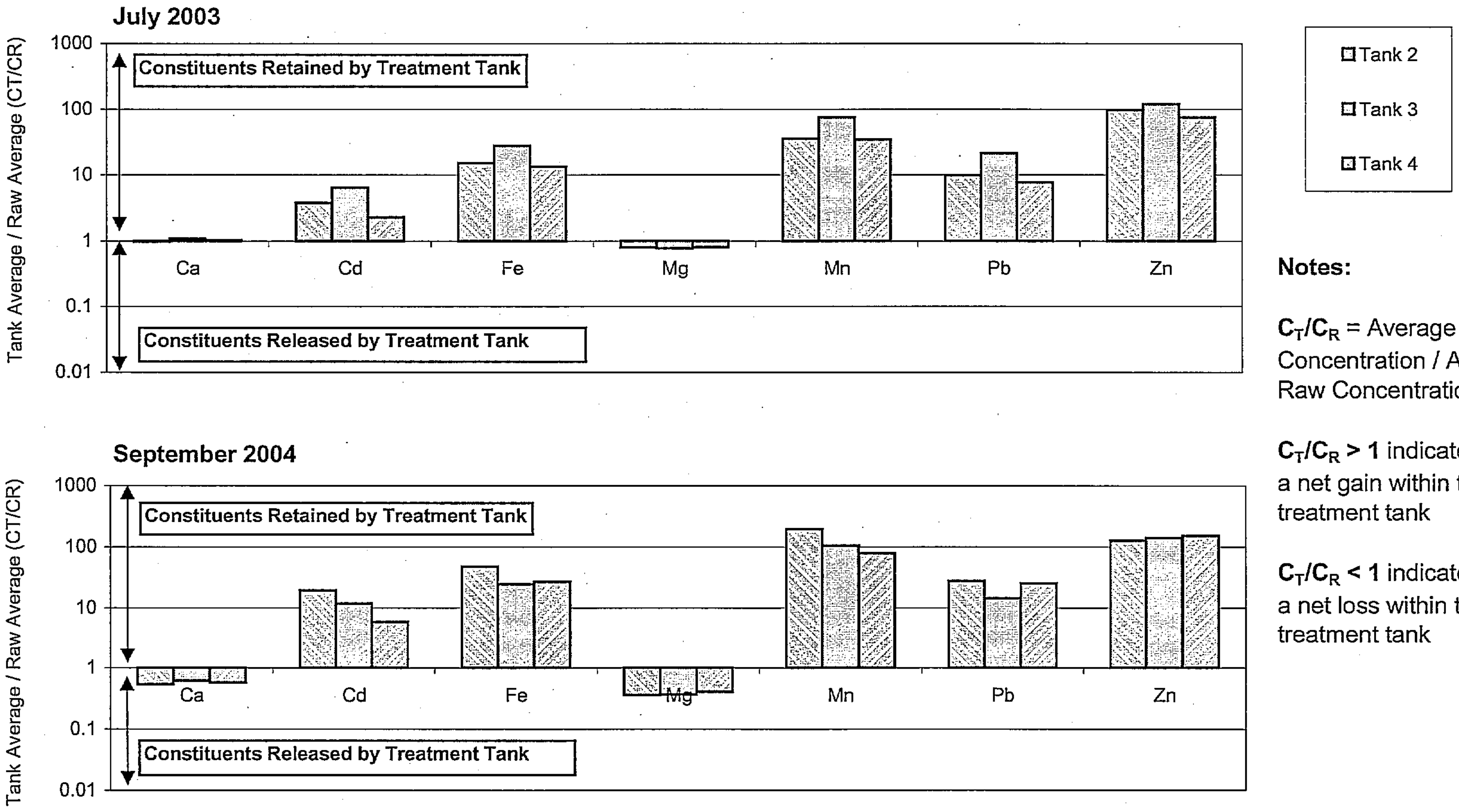
DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Fishbone Digest Data - Nov 04.xls	FIGURE NO.	19

MSE
Nevada Stewart Mine



Note:
Zero inch depth samples identify samples collected at surface.
Average concentrations calculated for the raw samples and for each tank.

Golder Associates	TITLE Solid Phase Concentrations - Zinc		
MSE Nevada Stewart Mine	DRAWN CR	DATE November 2004	JOB NO. 023-1166
	CHECKED RV	SCALE na	DWG. NO.
	REVIEWED RV	FILE NO. Fishbone Digest Data - Nov 04.xls	FIGURE NO. 20



Notes:

C_T/C_R = Average Tank Concentration / Average Raw Concentration

C_T/C_R **> 1** indicates a net gain within the treatment tank

C_T/C_R **< 1** indicates a net loss within the treatment tank

Golder Associates

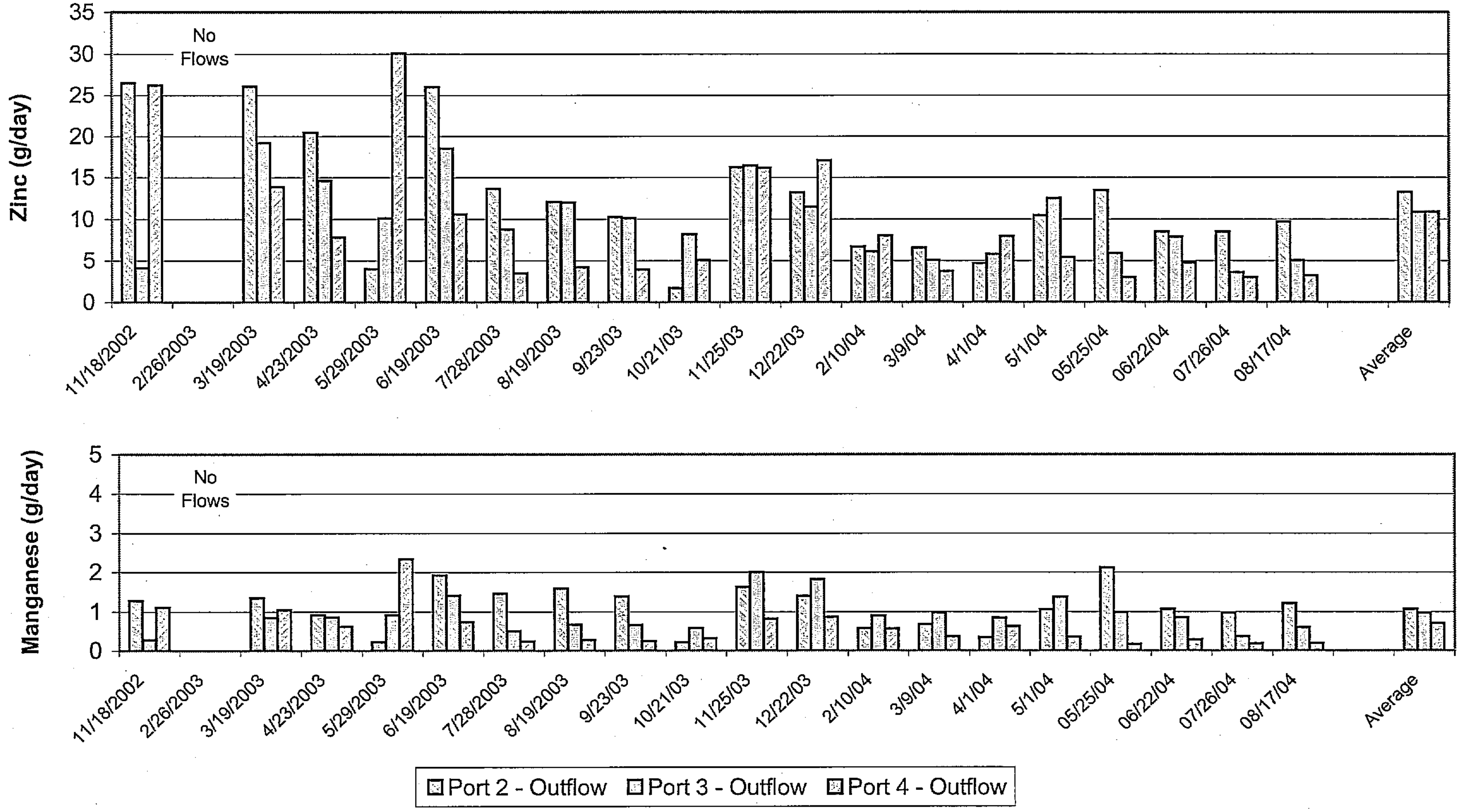
MSE

Nevada Stewart Mine

TITLE

Normalized Average Solid Phase Concentrations

DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Fishbone Digest Data - Nov 04.xls	FIGURE NO.	21



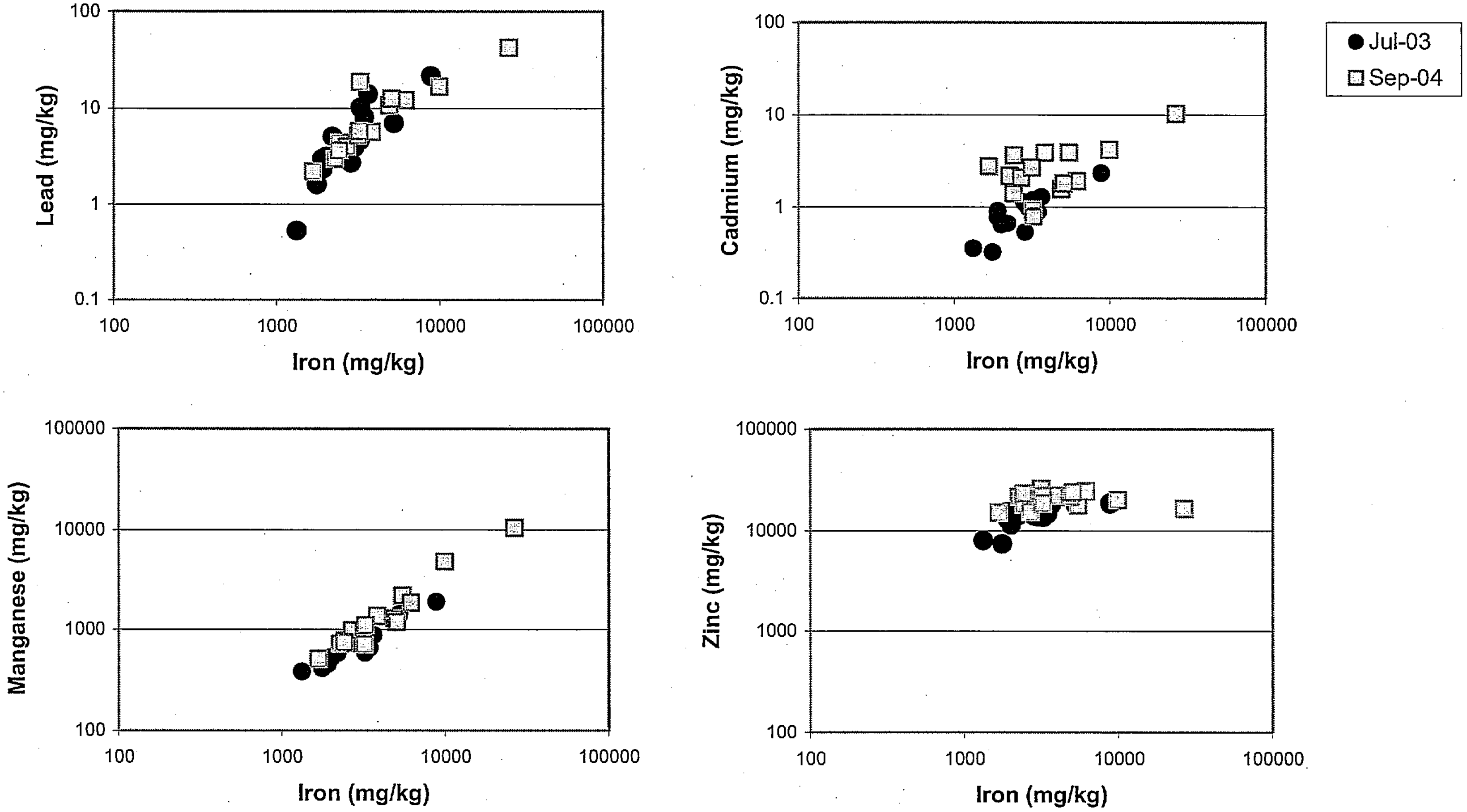
Golder Associates

MSE
Nevada Stewart Mine

TITLE

Treatment Tank Zinc and Manganese Attenuation

DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	MSE Data - Nov 2004.xls	FIGURE NO.	22



Golder Associates

MSE
Nevada Stewart Mine

TITLE
Solid Phase Metal Correlations (Fe vs. Pb, Cd, Mn and Zn)

DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	Fishbone Digest Data - Nov 04.xls	FIGURE NO.	23

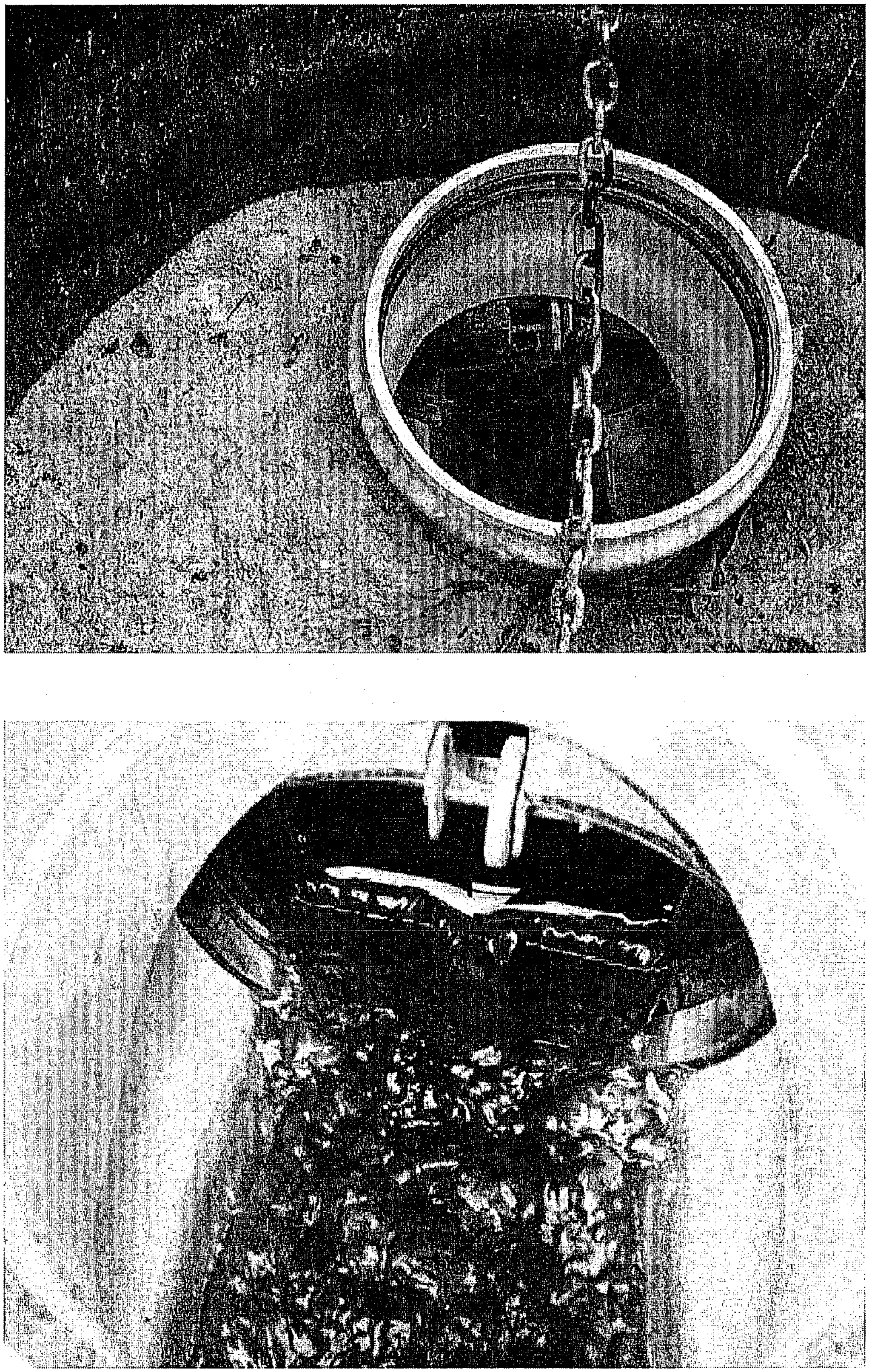
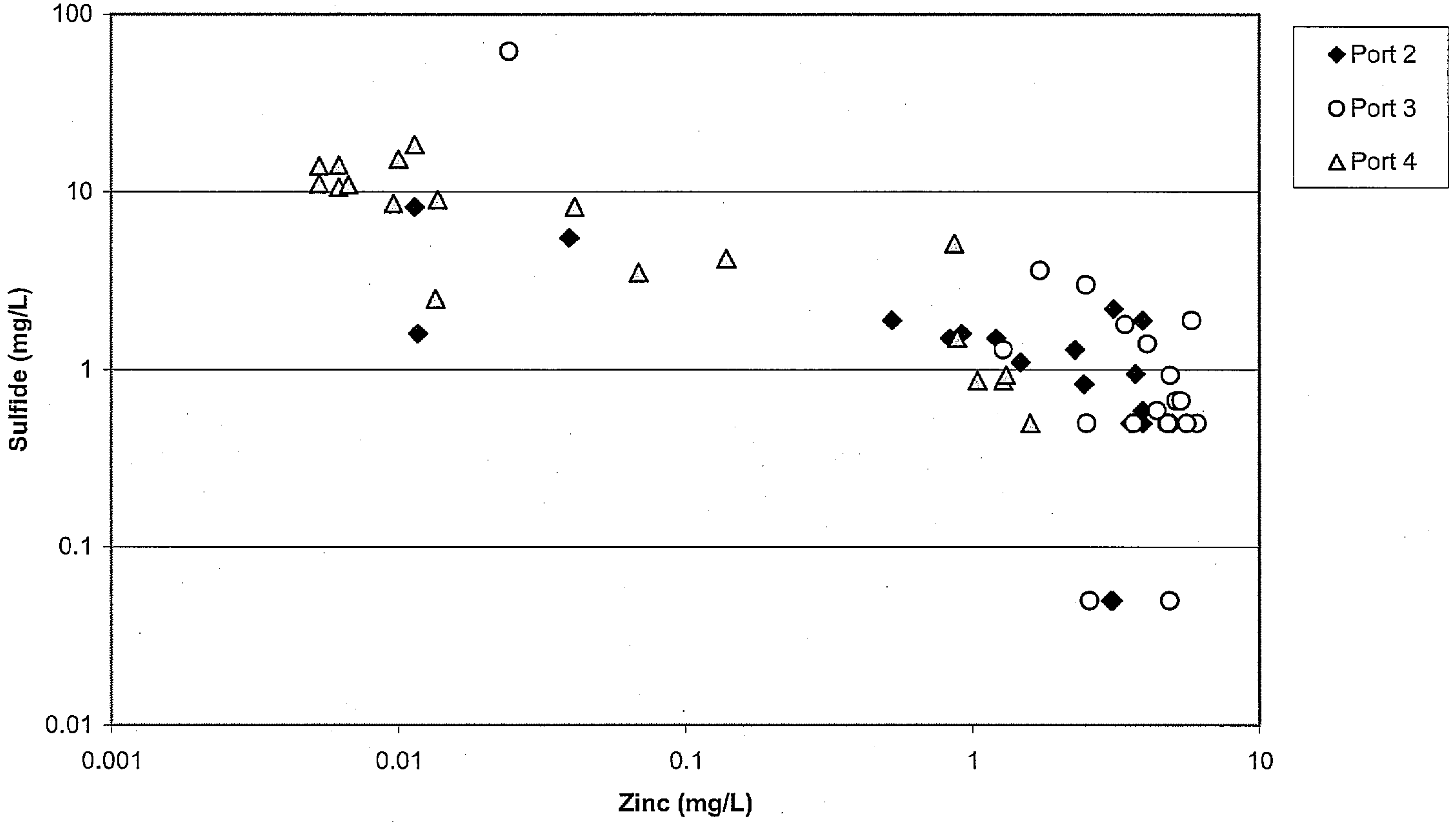


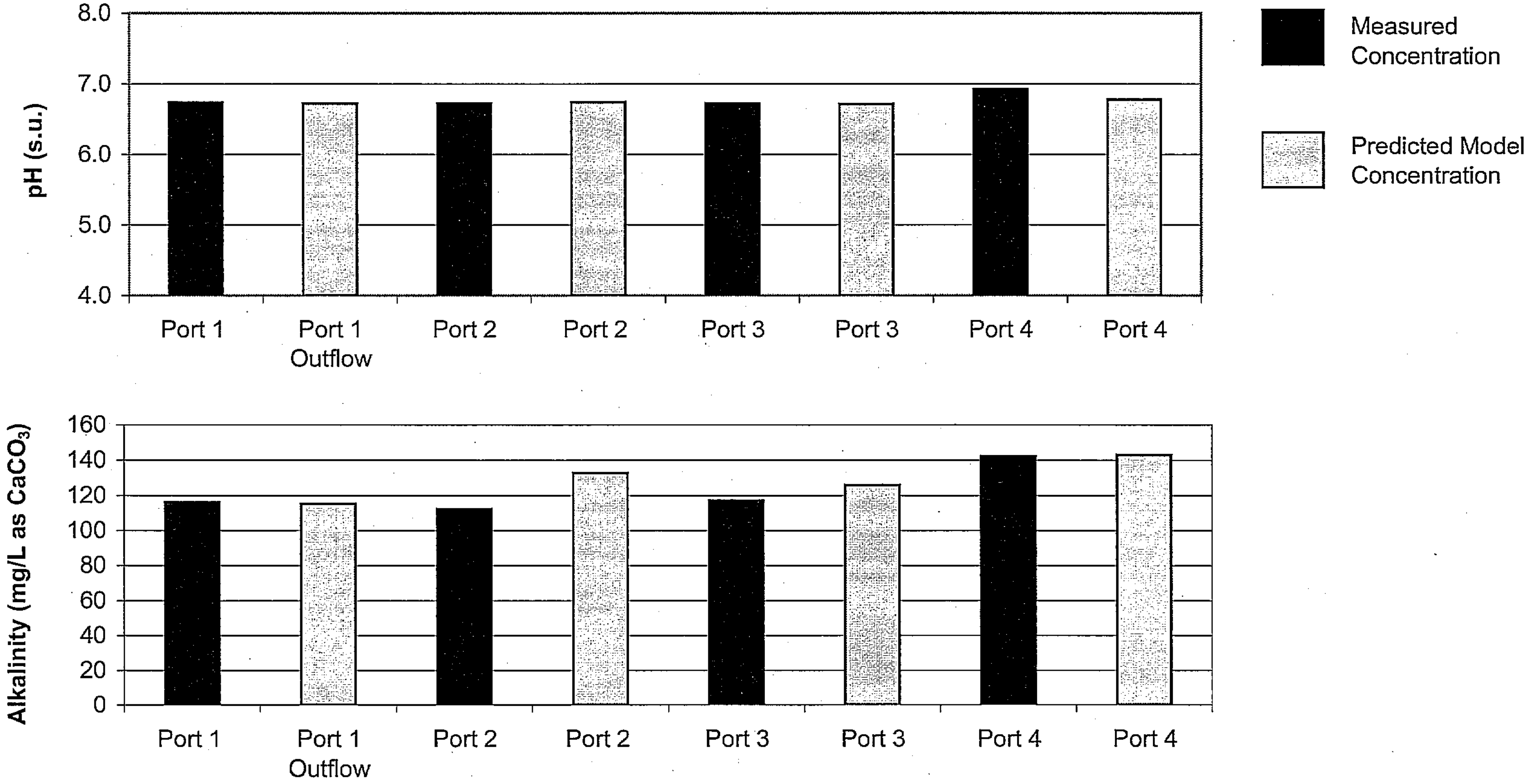
FIGURE 24

PORT 4 OUTFLOW AT LOW AND HIGH FLOW RATES

MSE/INTERSTATE MONITORING/ID



Golder Associates	TITLE **Treatment Tank Effluent Zinc Versus Sulfide**				
MSE **Nevada Stewart Mine**	DRAWN CR	DATE November 2004	JOB NO. 023-1166		
	CHECKED RV	SCALE na	DWG. NO.		
	REVIEWED RV	FILE NO. MSE Data - Nov 2004.xls	FIGURE NO. **25**		



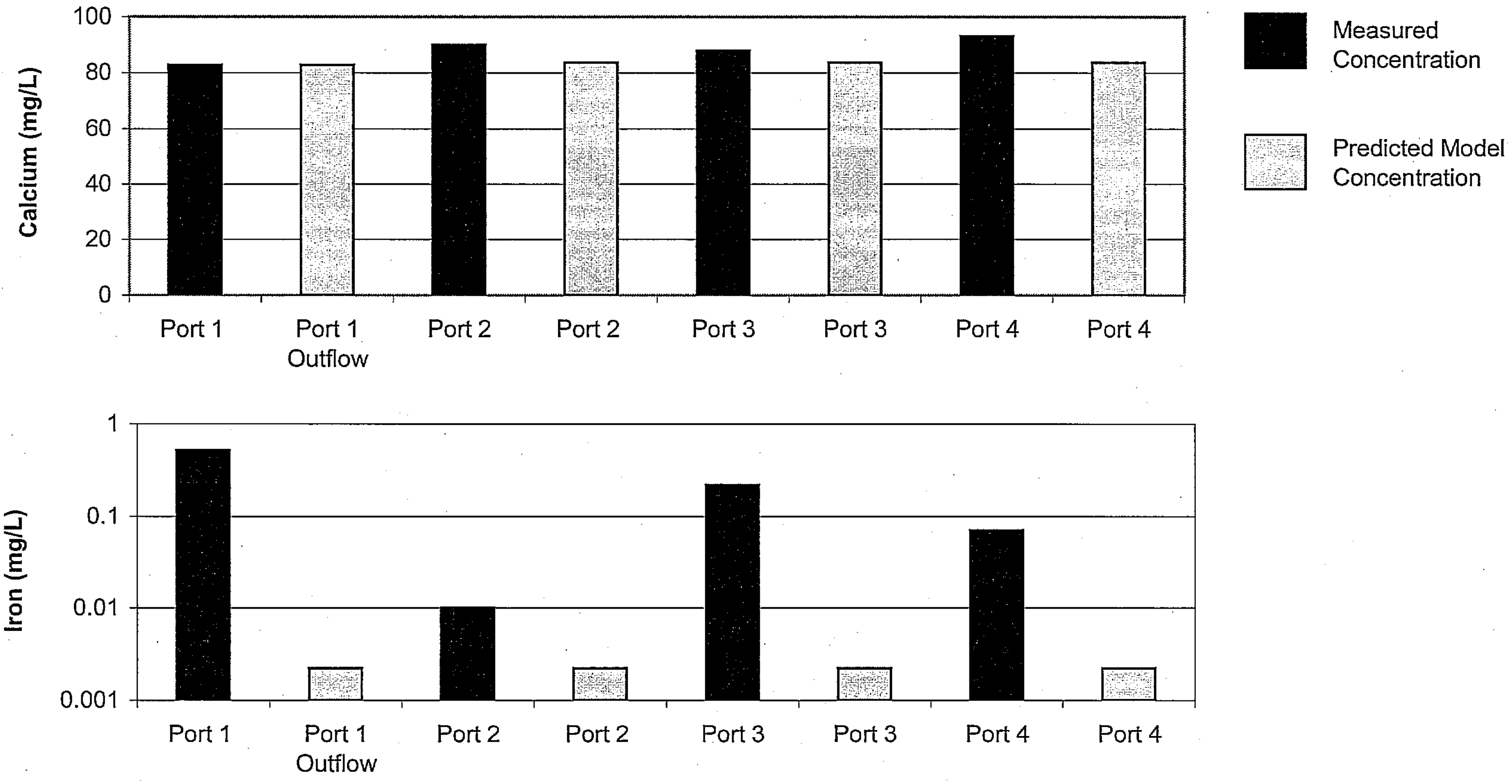
Golder Associates

TITLE

Geochemical Modeling Results - pH and Alkalinity

MSE
Nevada Stewart Mine

DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO	MSE Reaction Modeling - Nov 04.xls	FIGURE NO.	26



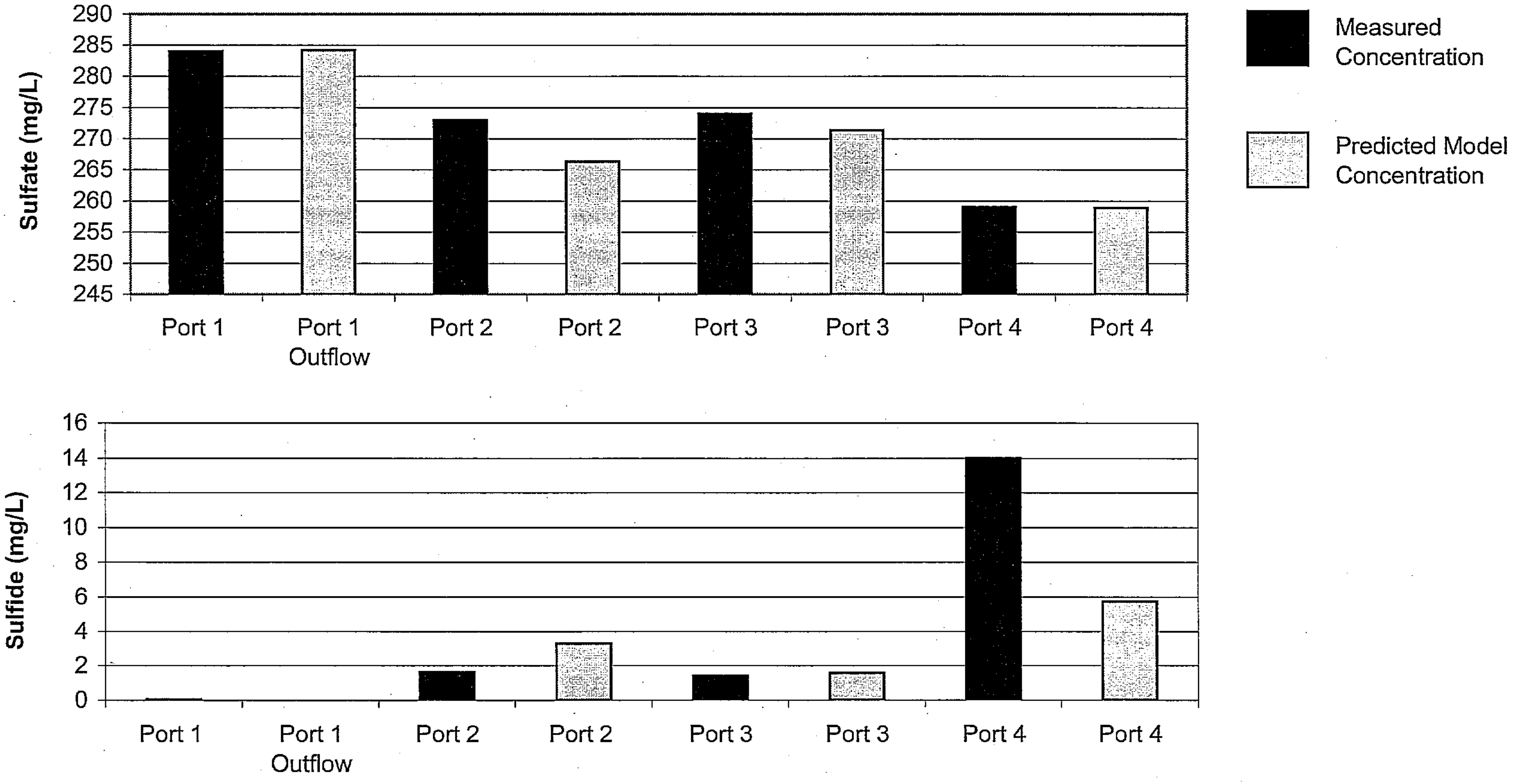
Golder Associates

TITLE

Geochemical Modeling Results - Calcium and Iron

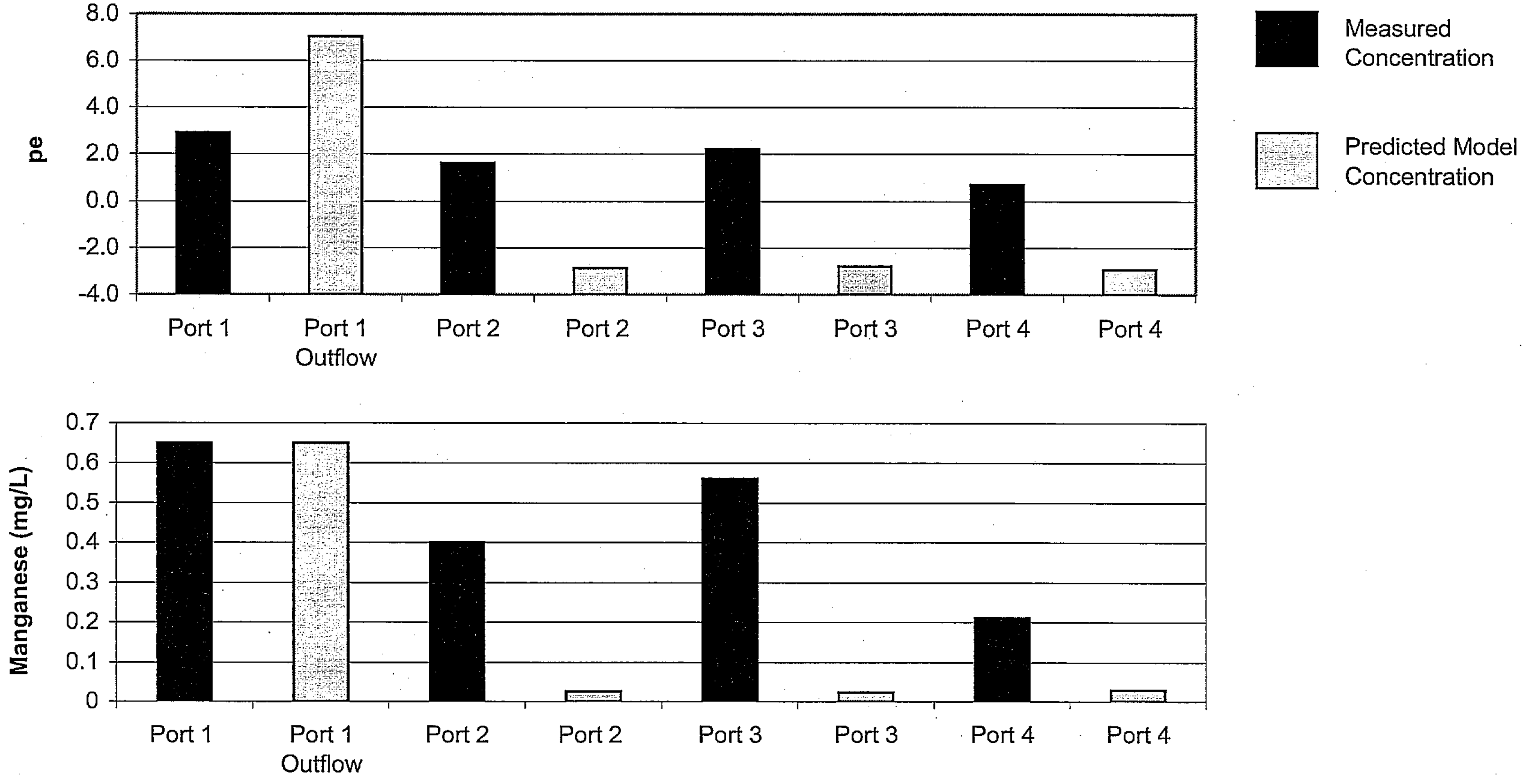
MSE
Nevada Stewart Mine

DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	MSE Reaction Modeling - Nov 04.xls	FIGURE NO.	27



Golder Associates

	TITLE					
	Geochemical Modeling Results - Sulfate and Sulfide					
MSE **Nevada Stewart Mine**	DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
	CHECKED	RV	SCALE	na	DWG. NO.	
	REVIEWED	RV	FILE NO.	MSE Reaction Modeling - Nov 04.xls	FIGURE NO.	28

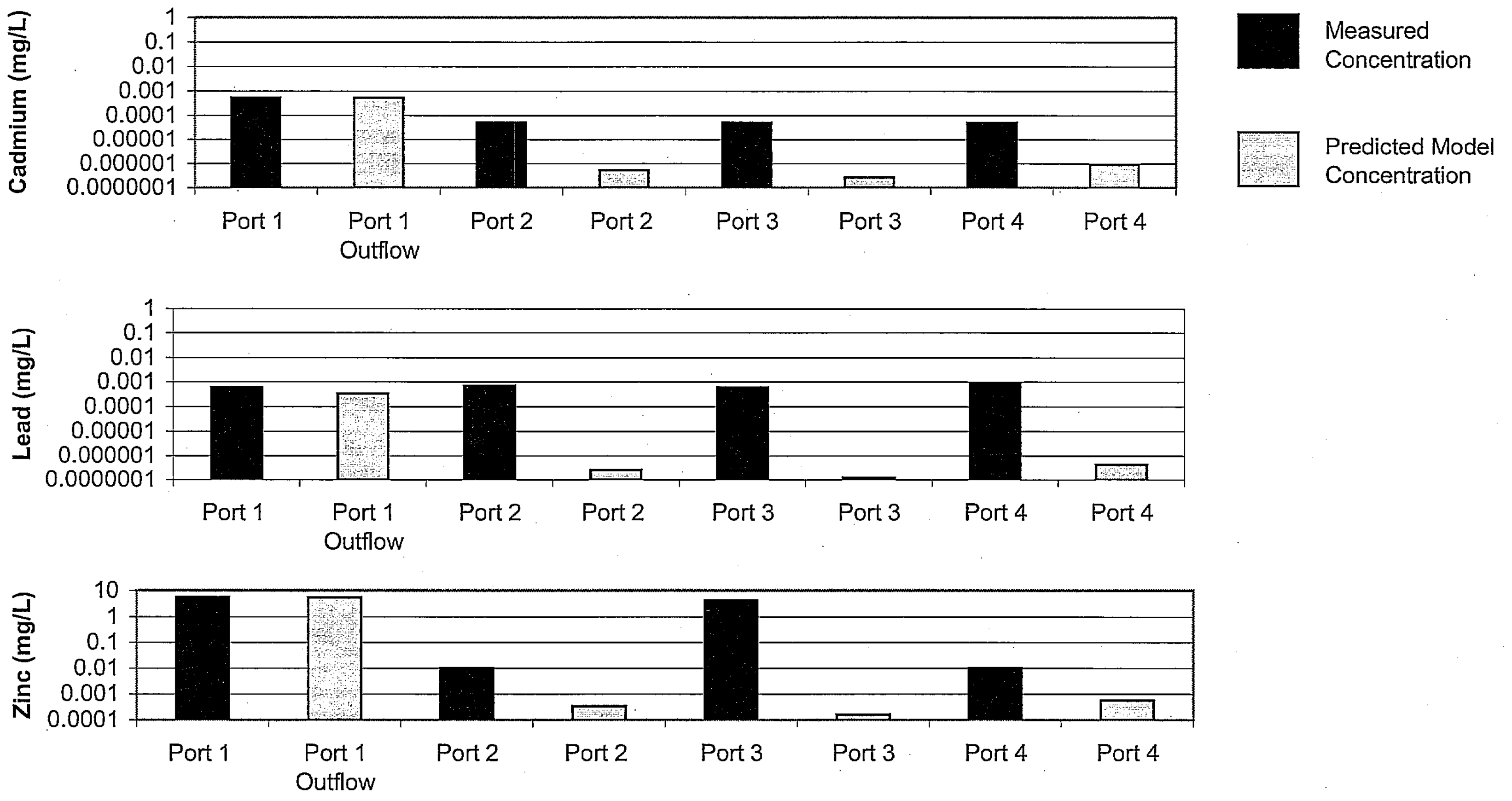


Golder Associates

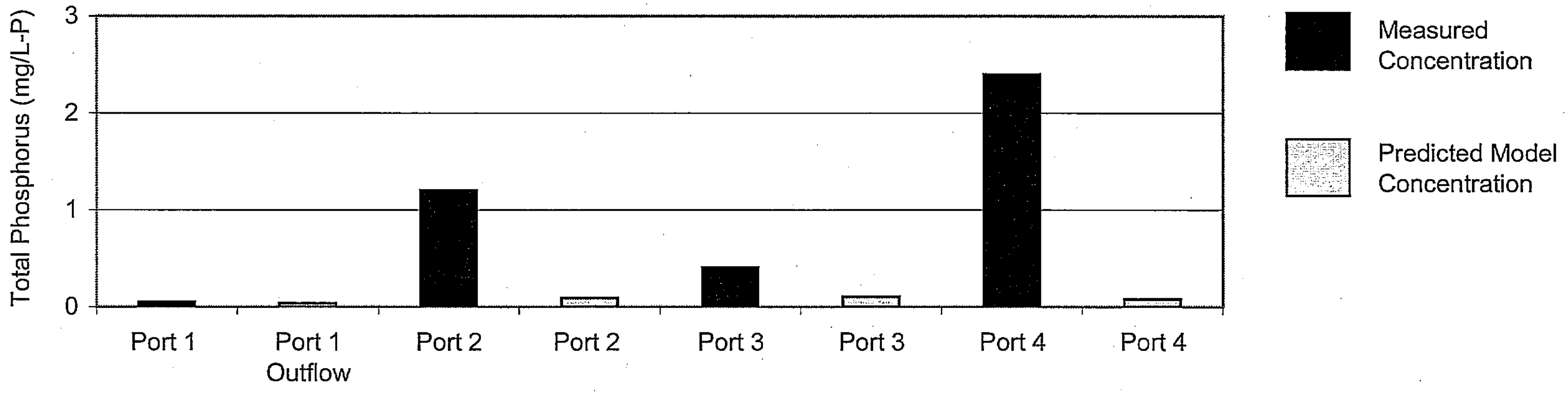
MSE
Nevada Stewart Mine

TITLE
Geochemical Modeling Results - pe and Manganese

DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	MSE Reaction Modeling - Nov 04.xls	FIGURE NO.	29



Golder Associates	TITLE **Geochemical Modeling Results - Cd, Pb and Zn**		
MSE **Nevada Stewart Mine**	DRAWN CR	DATE November 2004	JOB NO. 023-1166
	CHECKED RV	SCALE na	DWG. NO.
	REVIEWED RV	FILE NO. MSE Reaction Modeling - Nov 04.xls	FIGURE NO. 30



Golder Associates

TITLE

Geochemical Modeling Results - Phosphorus

MSE
Nevada Stewart Mine

DRAWN	CR	DATE	November 2004	JOB NO.	023-1166
CHECKED	RV	SCALE	na	DWG. NO.	
REVIEWED	RV	FILE NO.	MSE Reaction Modeling - Nov 04.xls	FIGURE NO.	31

APPENDIX A

```
      SELECTED_OUTPUT
      -file              MSEOct04.out
      -percent_error
      -ionic strengh
      -alkalinity
      -saturation_indices Calcite  Dolomite Gypsum
      otavite     Greenockite  Cd(OH)2(A)   CdSO4  CdSO4:H2O
      Cd3(PO4)2
      Fluorite
      Ferrihydrite  Siderite  Melanterite FeS(ppt) pyrite
      CO2(g)  O2(g)
      Magnesite  Epsomite
      Birnessite  Rhodochrosite  Manganite
      Mn3(PO4)2  MnHPO4(C)
      Anglesite  Cerrusite Galena  Hydcerrusite
      ClPyromorphite  Hxypyromorphite  Pb3(PO4)2  PbHPO4
      hydroxyapatite  vivianite  FCO3Apatite  Strengite
      SiO2(a)
      Smithsonite  Sphalerite  Wurtzite  Zn(OH)2(G)  Goslarite
      Zn3(PO4)2:4H2O
      Jarosite-K  Jarosite-Na  Jarosite-H
      Al(OH)3(a)  Al4(OH)10SO4  AlOHSO4  Gibbsite(c)  Boehmite
      Millerite  Ni(OH)2


      SOLUTION    1     A-1   NS Adit     18-Jul-02
      temp  9.8
      pH    6.8
      pe    8.4
      redox pe
      units mg/kgw
      density     1
      Al    0.0469
      Sb    0.0022
      As    0.0020
      Be    0.0012
      Cd    0.00027
      Ca    91.7
      Cr    0.010
      Cu    0.0015
      Fe    1.03
      Pb    0.0016
      Mg    41.8
      Mn    0.66
      Hg    0.0001
      Ni    0.0206
      K     0.55
      Se    0.0014
      Si    8.44  as Si
      Ag    0.0037
      Na    7.21
#     Ti    0.0006
      Zn    4.31
      P     0.1   as P
      Cl    5.0
      F     0.50
      S(6)  270   as SO4
      S(-2) 0.77  as S
      Alkalinity  120   as CaCO3
      N(-3) 0.05  as N
      N(5)  0.09  as N
      O(0)  2.42
      -water      1     #kg
      END

      SOLUTION    2     A-2   NS Adit     23-Jul-02
      temp  11.8
      pH    7.01
```

```
            pe     3.5
            redox pe
            units mg/kgw
            density      1
            Al     0.0469
            Sb     0.0024
            As     0.0034
            Be     0.0012
            Cd     0.00038
            Ca     89.7
            Cr     0.010
            Cu     0.0015
            Fe     0.66
            Pb     0.0015
            Mg     41.2
            Mn     0.56
            Hg     0.0001
            Ni     0.0206
            K      0.57
            Se     0.0017
            Si     8.23   as Si
            Ag     0.0037
            Na     7.12
    #       Ti     0.0016
            Zn     4.11
            P      0.1    as P
            Cl     5.0
            F      0.50
            S(6)   268    as SO4
            S(-2)  0.57   as S
            Alkalinity  116    as CaCO3
            N(-3)  0.05   as N
            N(5)   0.05   as N
    #       O(0)
            -water       1      #kg
            END

            SOLUTION     3      P1-1  Sample Port 1      18-Nov-02
            temp   9.9
            pH     6.76
            pe     3.0
            redox pe
            units mg/kgw
            density      1
            Al     0.0254
            Sb     0.0267
            As     0.0012
            Be     0.0011
            Cd     0.00029
            Ca     93.6
            Cr     0.009
            Cu     0.0014
            Fe     0.73
            Pb     0.0013
            Mg     42.7
            Mn     0.62
            Hg     0.0001
            Ni     0.0142
            K      0.58
            Se     0.0016
            Si     7.84   as Si
            Ag     0.0044
            Na     7.93
    #       Ti     0.0014
            Zn     5.64
            P      0.2    as P
            Cl     5.0
            F      0.50
```

```
        S(6)  257   as SO4
        S(-2) 0.50  as S
        Alkalinity  118   as CaCO3
        N(-3) 0.11  as N
        N(5)  0.05  as N
        O(0)  6.81
        -water      1     #kg
        END

        SOLUTION    4     P1-3  Port 1      19-Mar-03
        temp  9.8
        pH    6.83
        pe    4.0
        redox pe
        units mg/kgw
        density     1
#       Al
#       Sb
#       As
#       Be
        Cd    0.00079
        Ca    89.0
#       Cr
#       Cu
        Fe    0.49
        Pb    0.0008
        Mg    40.5
        Mn    0.66
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn    6.17
        P     0.1   as P
#       Cl
#       F
        S(6)  296   as SO4
        S(-2) 1.60  as S
        Alkalinity  114   as CaCO3
        N(-3) 0.07  as N
        N(5)  0.05  as N
#       O(0)
        -water      1     #kg
        END


        SOLUTION    5     P1-4  Port 1      23-Apr-03
        temp  9.98
        pH    6.73
        pe    2.9
        redox pe
        units mg/kgw
        density     1
#       Al
#       Sb
#       As
#       Be
        Cd    0.00053
        Ca    82.7
#       Cr
#       Cu
        Fe    0.52
        Pb    0.0006
        Mg    38.5
```

```
        Mn     0.65
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     5.52
        P      0.1    as P
#       Cl
#       F
        S(6)   284    as SO4
        S(-2)  0.05   as S
        Alkalinity  116   as CaCO3
        N(-3)  0.05   as N
        N(5)   0.08   as N
#       O(0)
        -water      1      #kg
        END


        SOLUTION     6      P2-1  Sample Port 2      18-Nov-02
        temp   9.7
        pH     6.67
        pe     -1.3
        redox pe
        units mg/kgw
        density     1
        Al     0.0254
        Sb     0.0267
        As     0.0012
        Be     0.0011
        Cd     0.00005
        Ca     98.8
        Cr     0.009
        Cu     0.0014
        Fe     0.14
        Pb     0.0013
        Mg     42.4
        Mn     0.35
        Hg     0.0001
        Ni     0.0142
        K      0.99
        Se     0.0016
        Si     7.87
        Ag     0.0044
        Na     8.60
#       Ti     0.0014
        Zn     0.04
        P      1.3    as P
        Cl     5.0
        F      0.50
        S(6)   254    as SO4
        S(-2)  5.50   as S
        Alkalinity  146   as CaCO3
        N(-3)  6.80   as N
        N(5)   0.06   as N
        O(0)   0.73
        -water      1      #kg
        END

        SOLUTION     7      P2-3  Port 2       19-Mar-03
        temp   9.61
        pH     6.58
        pe     2.6
        redox pe
```

```
        units mg/kgw
        density     1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00004
        Ca     96.7
#       Cr
#       Cu
        Fe     0.06
        Pb     0.0011
        Mg     40.7
        Mn     0.35
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     0.01
        P      2.0    as P
#       Cl
#       F
        S(6)   294    as SO4
        S(-2)  8.20   as S
        Alkalinity   126    as CaCO3
        N(-3)  0.87   as N
        N(5)   0.05   as N
#       O(0)
        -water       1      #kg
        END


        SOLUTION     8      P2-4  Port 2       23-Apr-03
        temp   9.83
        pH     6.72
        pe     1.6
        redox pe
        units mg/kgw
        density     1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00005
        Ca     89.8
#       Cr
#       Cu
        Fe     0.01
        Pb     0.0007
        Mg     39.8
        Mn     0.40
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     0.01
        P      1.2    as P
#       Cl
#       F
        S(6)   273    as SO4
```

```
        S(-2) 1.60  as S
        Alkalinity  112   as CaCO3
        N(-3) 0.68  as N
        N(5)  1.10  as N
#       O(0)
        -water      1     #kg
        END

        SOLUTION    9     P3-1  Sample Port 3     18-Nov-02
        temp  9.4
        pH    6.69
        pe    -0.7
        redox pe
        units mg/kgw
        density     1
        Al    0.0254
        Sb    0.0267
        As    0.0012
        Be    0.0013
        Cd    0.00007
        Ca    99.6
        Cr    0.009
        Cu    0.0030
        Fe    0.08
        Pb    0.0013
        Mg    41.7
        Mn    0.24
        Hg    0.0001
        Ni    0.0142
        K     1.63
        Se    0.0016
        Si    8.49
        Ag    0.0044
        Na    9.78
#       Ti    0.0014
        Zn    0.02
        P     7.8   as P
        Cl    5.0
        F     0.50
        S(6)  191   as SO4
        S(-2) 62.00 as S
        Alkalinity  288   as CaCO3
        N(-3) 32.90 as N
        N(5)  0.16  as N
        O(0)  1.56
        -water      1     #kg
        END

        SOLUTION    10    P3-3  Port 3      19-Mar-03
        temp  9.64
        pH    6.76
        pe    2.6
        redox pe
        units mg/kgw
        density     1
#       Al
#       Sb
#       As
#       Be
        Cd    0.00004
        Ca    90.8
#       Cr
#       Cu
        Fe    0.02
        Pb    0.0008
        Mg    40.0
        Mn    0.50
```

```
#     Hg
#     Ni
#     K
#     Se
#     Si
#     Ag
#     Na
#     Ti
      Zn     2.49
      P      0.9    as P
#     Cl
#     F
      S(6)   296    as SO4
      S(-2)  3.00   as S
      Alkalinity    121    as CaCO3
      N(-3)  0.38   as N
      N(5)   0.05   as N
#     O(0)
      -water        1      #kg
      END


      SOLUTION      11     P3-4  Port 3      23-Apr-03
      temp   9.85
      pH     6.72
      pe     2.2
      redox pe
      units mg/kgw
      density       1
#     Al
#     Sb
#     As
#     Be
      Cd     0.00005
      Ca     87.9
#     Cr
#     Cu
      Fe     0.22
      Pb     0.0006
      Mg     39.7
      Mn     0.56
#     Hg
#     Ni
#     K
#     Se
#     Si
#     Ag
#     Na
#     Ti
      Zn     4.08
      P      0.4    as P
#     Cl
#     F
      S(6)   274    as SO4
      S(-2)  1.40   as S
      Alkalinity    117    as CaCO3
      N(-3)  0.43   as N
      N(5)   0.70   as N
#     O(0)
      -water        1      #kg
      END


      SOLUTION      12     P4-1  Sample Port 4     18-Nov-02
      temp   9.7
      pH     6.81
      pe     -1.5
      redox pe
```

```
       units mg/kgw
       density     1
       Al    0.0254
       Sb    0.0267
       As    0.0012
       Be    0.0011
       Cd    0.00005
       Ca    99.5
       Cr    0.009
       Cu    0.0019
       Fe    0.14
       Pb    0.0013
       Mg    41.8
       Mn    0.38
       Hg    0.0001
       Ni    0.0142
       K     0.64
       Se    0.0016
       Si    7.88
       Ag    0.0044
       Na    7.93
#      Ti    0.0014
       Zn    0.07
       P     1.3   as P
       Cl    5.0
       F     0.50
       S(6)  259   as SO4
       S(-2) 3.50  as S
       Alkalinity  135   as CaCO3
       N(-3) 3.00  as N
       N(5)  2.90  as N
       O(0)  0.71
       -water      1     #kg
       END

       SOLUTION    13    P4-3  Port 4      19-Mar-03
       temp  9.33
       pH    6.9
       pe    2.0
       redox pe
       units mg/kgw
       density     1
#      Al
#      Sb
#      As
#      Be
       Cd    0.00004
       Ca    95.3
#      Cr
#      Cu
       Fe    0.12
       Pb    0.0010
       Mg    39.8
       Mn    0.20
#      Hg
#      Ni
#      K
#      Se
#      Si
#      Ag
#      Na
#      Ti
       Zn    0.01
       P     2.7   as P
#      Cl
#      F
       S(6)  280   as SO4
       S(-2) 18.60 as S
```

```
        Alkalinity  141    as CaCO3
        N(-3) 1.50   as N
        N(5)  0.05   as N
#       O(0)
        -water       1      #kg
        END

        SOLUTION     14     P4-4  Port 4       23-Apr-03
        temp  9.73
        pH    6.92
        pe    0.7
        redox pe
        units mg/kgw
        density      1
#       Al
#       Sb
#       As
#       Be
        Cd    0.00005
        Ca    93.0
#       Cr
#       Cu
        Fe    0.07
        Pb    0.0009
        Mg    39.4
        Mn    0.21
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn    0.01
        P     2.4    as P
#       Cl
#       F
        S(6)  259    as SO4
        S(-2) 14.00  as S
        Alkalinity  142    as CaCO3
        N(-3) 1.50   as N
        N(5)  0.89   as N
#       O(0)
        -water       1      #kg
        END

        SOLUTION     15     P1-5  Port 1       29-May-03
        temp  10.1
        pH    6.61
        pe    3.3
        redox pe
        units mg/kgw
        density      1
#       Al
#       Sb
#       As
#       Be
        Cd    0.00044
        Ca    88.8
#       Cr
#       Cu
        Fe    0.62
        Pb    0.0006
        Mg    41.1
        Mn    0.65
#       Hg
#       Ni
```

```
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     5.81
        P      0.2    as P
#       Cl
#       F
        S(6)   273    as SO4
        S(-2)  0.05   as S
        Alkalinity    120    as CaCO3
        N(-3)  0.05   as N
        N(5)   0.05   as N
        O(0)   6.45
        -water        1      #kg
        END


        SOLUTION      16     P1-6   Port 1       19-Jun-03
        temp   10.09
        pH     6.1
        pe     5.0
        redox pe
        units mg/kgw
        density       1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00038
        Ca     95.7
#       Cr
#       Cu
        Fe     0.68
        Pb     0.0015
        Mg     41.6
        Mn     0.68
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     6.42
        P      0.1    as P
#       Cl
#       F
        S(6)   282    as SO4
        S(-2)  0.05   as S
        Alkalinity    120    as CaCO3
        N(-3)  0.05   as N
        N(5)   0.05   as N
        O(0)   6.05
        -water        1      #kg
        END

        SOLUTION      17     P1-7   Port 1       28-Jul-03
        temp   10.05
        pH     5.38
        pe     5.6
        redox pe
        units mg/kgw
        density       1
#       Al
```

```
#       Sb
#       As
#       Be
        Cd      0.00038
        Ca      94.0
#       Cr
#       Cu
        Fe      0.69
        Pb      0.0019
        Mg      42.6
        Mn      0.61
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn      6.33
        P       0.2     as P
#       Cl
#       F
        S(6)    296     as SO4
        S(-2)   0.05    as S
        Alkalinity      119     as CaCO3
        N(-3)   0.05    as N
        N(5)    0.09    as N
        O(0)    10.84
        -water          1       #kg
        END

        SOLUTION        18      P1-8    Port 1          19-Aug-03
        temp    10.14
        pH      5.33
        pe      4.0
        redox pe
        units mg/kgw
        density         1
#       Al
#       Sb
#       As
#       Be
        Cd      0.00022
        Ca      90.7
#       Cr
#       Cu
        Fe      0.54
        Pb      0.0007
        Mg      10.9
        Mn      0.58
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn      6.43
        P       0.2     as P
#       Cl
#       F
        S(6)    283     as SO4
        S(-2)   0.50    as S
        Alkalinity      118     as CaCO3
        N(-3)   0.05    as N
        N(5)    0.05    as N
```

```
        O(0)  9.49
        -water       1     #kg
        END

        SOLUTION     19    P2-5  Port 2      29-May-03
        temp  9.99
        pH    6.11
        pe    2.7
        redox pe
        units mg/kgw
        density      1
#       Al
#       Sb
#       As
#       Be
        Cd    0.00005
        Ca    93.2
#       Cr
#       Cu
        Fe    0.01
        Pb    0.0006
        Mg    41.6
        Mn    0.42
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn    1.47
        P     1.1   as P
#       Cl
#       F
        S(6)  277   as SO4
        S(-2) 1.10  as S
        Alkalinity  124   as CaCO3
        N(-3) 0.38  as N
        N(5)  1.30  as N
        O(0)  0.69
        -water       1     #kg
        END

        SOLUTION     20    P2-6  Port 2      19-Jun-03
        temp  10.26
        pH    6.54
        pe    3.2
        redox pe
        units mg/kgw
        density      1
#       Al
#       Sb
#       As
#       Be
        Cd    0.00005
        Ca    95.8
#       Cr
#       Cu
        Fe    0.03
        Pb    0.0017
        Mg    41.4
        Mn    0.27
#       Hg
#       Ni
#       K
#       Se
#       Si
```

```
#       Ag
#       Na
#       Ti
        Zn      0.92
        P       1.4     as P
#       Cl
#       F
        S(6)    277     as SO4
        S(-2)   1.60    as S
        Alkalinity      125     as CaCO3
        N(-3)   0.76    as N
        N(5)    1.30    as N
        O(0)    0.30
        -water          1       #kg
        END

        SOLUTION        21      P2-7    Port 2          28-Jul-03
        temp    10.24
        pH      6.3
        pe      3.8
        redox pe
        units mg/kgw
        density         1
#       Al
#       Sb
#       As
#       Be
        Cd      0.00009
        Ca      98.0
#       Cr
#       Cu
        Fe      0.01
        Pb      0.0020
        Mg      43.4
        Mn      0.26
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn      3.11
        P       0.8     as P
#       Cl
#       F
        S(6)    300     as SO4
        S(-2)   2.20    as S
        Alkalinity      122     as CaCO3
        N(-3)   0.25    as N
        N(5)    1.10    as N
        O(0)    1.48
        -water          1       #kg
        END

        SOLUTION        22      P2-8    Port 2          19-Aug-03
        temp    10.16
        pH      6.38
        pe      3.0
        redox pe
        units mg/kgw
        density         1
#       Al
#       Sb
#       As
#       Be
        Cd      0.00005
```

```
      Ca    93.3
#     Cr
#     Cu
      Fe    0.01
      Pb    0.0007
      Mg    41.5
      Mn    0.20
#     Hg
#     Ni
#     K
#     Se
#     Si
#     Ag
#     Na
#     Ti
      Zn    3.55
      P     0.8   as P
#     Cl
#     F
      S(6)  297   as SO4
      S(-2) 0.50  as S
      Alkalinity  117   as CaCO3
      N(-3) 0.13  as N
      N(5)  0.27  as N
      O(0)  2.04
      -water      1     #kg
      END

      SOLUTION    23    P3-5  Port 3     29-May-03
      temp  10.02
      pH    6.18
      pe    3.0
      redox pe
      units mg/kgw
      density     1
#     Al
#     Sb
#     As
#     Be
      Cd    0.00006
      Ca    90.5
#     Cr
#     Cu
      Fe    0.44
      Pb    0.0006
      Mg    41.8
      Mn    0.57
#     Hg
#     Ni
#     K
#     Se
#     Si
#     Ag
#     Na
#     Ti
      Zn    4.87
      P     0.4   as P
#     Cl
#     F
      S(6)  268   as SO4
      S(-2) 0.05  as S
      Alkalinity  124   as CaCO3
      N(-3) 0.20  as N
      N(5)  0.47  as N
      O(0)  5.28
      -water      1     #kg
      END
```

```
            SOLUTION    24    P3-6  Port 3      19-Jun-03
            temp  10.61
            pH    6.56
            pe    3.1
            redox pe
            units mg/kgw
            density     1
#           Al
#           Sb
#           As
#           Be
            Cd    0.00006
            Ca    98.2
#           Cr
#           Cu
            Fe    0.37
            Pb    0.0018
            Mg    42.0
            Mn    0.29
#           Hg
#           Ni
#           K
#           Se
#           Si
#           Ag
#           Na
#           Ti
            Zn    1.28
            P     1.2   as P
#           Cl
#           F
            S(6)  258   as SO4
            S(-2) 1.30  as S
            Alkalinity  128   as CaCO3
            N(-3) 0.89  as N
            N(5)  1.10  as N
            O(0)  0.95
            -water      1     #kg
            END

            SOLUTION    25    P3-7  Port 3      28-Jul-03
            temp  10.57
            pH    6.62
            pe    3.7
            redox pe
            units mg/kgw
            density     1
#           Al
#           Sb
#           As
#           Be
            Cd    0.00005
            Ca    96.9
#           Cr
#           Cu
            Fe    0.58
            Pb    0.0019
            Mg    43.2
            Mn    0.35
#           Hg
#           Ni
#           K
#           Se
#           Si
#           Ag
#           Na
#           Ti
            Zn    1.72
```

```
        P      1.0   as P
#       Cl
#       F
        S(6)   292   as SO4
        S(-2) 3.60   as S
        Alkalinity  129    as CaCO3
        N(-3) 0.94   as N
        N(5)  0.42   as N
        O(0)  4.49
        -water       1      #kg
        END

        SOLUTION     26     P3-8  Port 3       19-Aug-03
        temp  10.29
        pH    6.52
        pe    3.1
        redox pe
        units mg/kgw
        density      1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00005
        Ca     91.6
#       Cr
#       Cu
        Fe     0.35
        Pb     0.0007
        Mg     41.0
        Mn     0.41
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     3.41
        P      0.7   as P
#       Cl
#       F
        S(6)   286   as SO4
        S(-2) 1.80   as S
        Alkalinity  120    as CaCO3
        N(-3) 0.44   as N
        N(5)  0.05   as N
        O(0)  5.86
        -water       1      #kg
        END

        SOLUTION     27     P4-5  Port 4       29-May-03
        temp  10.02
        pH    6.01
        pe    2.8
        redox pe
        units mg/kgw
        density      1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00005
        Ca     97.2
#       Cr
#       Cu
        Fe     0.06
```

```
        Pb     0.0006
        Mg     41.5
        Mn     0.20
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     0.01
        P      2.6    as P
#       Cl
#       F
        S(6)   262    as SO4
        S(-2)  11.10  as S
        Alkalinity  153   as CaCO3
        N(-3)  1.90   as N
        N(5)   1.10   as N
        O(0)   0.20
        -water        1      #kg
        END

        SOLUTION      28     P4-6  Port 4       19-Jun-03
        temp   10.4
        pH     6.05
        pe     2.4
        redox pe
        units mg/kgw
        density       1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00005
        Ca     101.0
#       Cr
#       Cu
        Fe     0.17
        Pb     0.0017
        Mg     41.7
        Mn     0.24
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     0.01
        P      2.4    as P
#       Cl
#       F
        S(6)   254    as SO4
        S(-2)  9.00   as S
        Alkalinity  141   as CaCO3
        N(-3)  1.50   as N
        N(5)   1.30   as N
        O(0)   0.59
        -water        1      #kg
        END

        SOLUTION      29     P4-7  Port 4       28-Jul-03
        temp   10.91
        pH     6.73
        pe     2.8
```

```
        redox pe
        units mg/kgw
        density     1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00005
        Ca     101.0
#       Cr
#       Cu
        Fe     0.11
        Pb     0.0021
        Mg     42.9
        Mn     0.17
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     0.01
        P      2.5    as P
#       Cl
#       F
        S(6)   286    as SO4
        S(-2) 14.10 as S
        Alkalinity  140    as CaCO3
        N(-3) 1.60  as N
        N(5)  0.49  as N
        O(0)  0.56
        -water      1      #kg
        END

        SOLUTION    30     P4-8  Port 4      19-Aug-03
        temp  10.97
        pH    6.25
        pe    2.9
        redox pe
        units mg/kgw
        density     1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00005
        Ca     97.3
#       Cr
#       Cu
        Fe     0.08
        Pb     0.0007
        Mg     40.6
        Mn     0.17
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     0.01
        P      2.5    as P
#       Cl
#       F
        S(6)   286    as SO4
```

```
        S(-2) 10.60 as S
        Alkalinity  138   as CaCO3
        N(-3) 1.70  as N
        N(5)  0.05  as N
        O(0)  0.36
        -water      1     #kg
        END

#       DATA ADDED FOR JULY 2004 REPORT

        SOLUTION    32    P1-9  Port 1      23-Sep-03
        temp  9.96
        pH    6.4
        pe    4.3
        redox pe
        units mg/kgw
        density     1
#       Al
#       Sb
#       As
#       Be
        Cd    0.00041
        Ca    96.1
#       Cr
#       Cu
        Fe    0.595
        Pb    0.00078
        Mg    42.3
        Mn    0.602
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn    7.16
        P     1.42  as P
#       Cl
#       F
        S(6)  325   as SO4
        S(-2) 0.50  as S
        Alkalinity  118   as CaCO3
        N(-3) 0.05  as N
        N(5)  0.07  as N
        O(0)  6.09
        -water      1     #kg
        END

        SOLUTION    33    P1-10 Port 1      21-Oct-03
        temp  9.92
        pH    6.56
        pe    3.1
        redox pe
        units mg/kgw
        density     1
        Al    0.0311
        Sb    0.0399
        As    0.0007
        Be    0.0017
        Cd    0.00046
        Ca    103.0
        Cr    0.009
        Cu    0.0014
        Fe    0.758
        Pb    0.0021
        Mg    44.3
```

```
        Mn     0.64
        Hg     0.0001
        Ni     0.0221
        K      0.59
        Se     0.0012
        Si     7.72
        Ag     0.0003
        Na     7.76
#       Ti     0.0018
        Zn     7.78
        P      2.2    as P
        Cl     5.0
        F      0.50
        S(6)   305    as SO4
        S(-2)  0.50   as S
        Alkalinity    118    as CaCO3
        N(-3)  0.05   as N
        N(5)   0.05   as N
        O(0)   6.50
        -water        1      #kg
        END

        SOLUTION      34     P1-11 Port 1      25-Nov-03
        temp   9.66
        pH     6.65
        pe     3.0
        redox pe
        units mg/kgw
        density       1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00039
        Ca     101.0
#       Cr
#       Cu
        Fe     0.868
        Pb     0.0008
        Mg     43.6
        Mn     0.646
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     7.53
        P      0.1    as P
#       Cl
#       F
        S(6)   295    as SO4
        S(-2)  0.05   as S
        Alkalinity    120    as CaCO3
        N(-3)  0.06   as N
        N(5)   0.18   as N
        O(0)   6.73
        -water        1      #kg
        END

        SOLUTION      35     P1-12 Port 1      22-Dec-03
        temp   9.69
        pH     6.26
        pe     4.1
        redox pe
        units mg/kgw
```

```
        density      1
#       Al
#       Sb
#       As
#       Be
        Cd      0.00078
        Ca      93.2
#       Cr
#       Cu
        Fe      0.657
        Pb      0.00094
        Mg      40.9
        Mn      0.607
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn      7.12
        P       0.16   as P
#       Cl
#       F
        S(6)    296    as SO4
        S(-2)   0.05   as S
        Alkalinity  112    as CaCO3
        N(-3)   0.05   as N
        N(5)    0.06   as N
        O(0)    7.09
        -water       1      #kg
        END

        SOLUTION     36     P1-13 Port 1       10-Feb-04
        temp    9.34
        pH      6.21
        pe      4.1
        redox pe
        units mg/kgw
        density      1
#       Al
#       Sb
#       As
#       Be
        Cd      0.00140
        Ca      91.7
#       Cr
#       Cu
        Fe      0.749
        Pb      0.00072
        Mg      39.0
        Mn      0.629
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn      7.06
        P       0.06   as P
#       Cl
#       F
        S(6)    269    as SO4
        S(-2)   0.50   as S
        Alkalinity  112    as CaCO3
```

```
        N(-3) 0.05   as N
        N(5)  0.05   as N
        O(0)  6.32
        -water       1      #kg
        END

        SOLUTION     37     P1-14 Port 1       9-Mar-04
        temp  9.67
        pH    6.13
        pe    5.2
        redox pe
        units mg/kgw
        density      1
#       Al
#       Sb
#       As
#       Be
        Cd    0.00086
        Ca    88.9
#       Cr
#       Cu
        Fe    0.348
        Pb    0.0012
        Mg    38.7
        Mn    0.688
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn    6.31
        P     0.12   as P
#       Cl
#       F
        S(6)  289    as SO4
        S(-2) 0.05   as S
        Alkalinity   116    as CaCO3
        N(-3) 0.08   as N
        N(5)  0.13   as N
        O(0)  6.87
        -water       1      #kg
        END

        SOLUTION     38     P1-15 Port 1       1-Apr-04
        temp  9.8
        pH    6.35
        pe    4.8
        redox pe
        units mg/kgw
        density      1
#       Al
#       Sb
#       As
#       Be
        Cd    0.00059
        Ca    95.0
#       Cr
#       Cu
        Fe    0.192
        Pb    0.0012
        Mg    40.9
        Mn    0.639
#       Hg
#       Ni
#       K
```

```
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     7.01
        P      0.1    as P
#       Cl
#       F
        S(6)   291    as SO4
        S(-2) 0.05    as S
        Alkalinity  112    as CaCO3
        N(-3) 0.08    as N
        N(5)   0.07   as N
        O(0)   6.52
        -water        1      #kg
        END

        SOLUTION      39     P1-16 Port 1       1-May-04
        temp   9.98                 #4/29/04
        pH     5.74
        pe     4.5
        redox pe
        units mg/kgw
        density       1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00041
        Ca     96.4
#       Cr
#       Cu
        Fe     0.344
        Pb     0.00054
        Mg     41.3
        Mn     0.605
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     7.11
        P      0.05   as P
#       Cl
#       F
        S(6)   317    as SO4
        S(-2) 0.05    as S
        Alkalinity  114    as CaCO3
        N(-3) 0.21    as N
        N(5)   0.05   as N
        O(0)   6.38
        -water        1      #kg
        END

        SOLUTION      40     P2-9  Port 2       23-Sep-03
        temp   10
        pH     6.61
        pe     3.9
        redox pe
        units mg/kgw
        density       1
#       Al
#       Sb
#       As
```

```
#       Be
        Cd     0.00005
        Ca     101.0
#       Cr
#       Cu
        Fe     0.0102
        Pb     0.00078
        Mg     42.9
        Mn     0.164
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     3.92
        P      2.26   as P
#       Cl
#       F
        S(6)   331    as SO4
        S(-2)  0.50   as S
        Alkalinity    117    as CaCO3
        N(-3)  0.14   as N
        N(5)   0.38   as N
        O(0)   0.87
        -water        1      #kg
        END

        SOLUTION      41     P2-10 Port 2      21-Oct-03
        temp   9.91
        pH     6.52
        pe     3.2
        redox pe
        units mg/kgw
        density       1
        Al     0.0311
        Sb     0.0399
        As     0.0006
        Be     0.0017
        Cd     0.00004
        Ca     104.0
        Cr     0.009
        Cu     0.0014
        Fe     0.0848
        Pb     0.0018
        Mg     43.7
        Mn     0.162
        Hg     0.0001
        Ni     0.0221
        K      0.60
        Se     0.0012
        Si     7.59
        Ag     0.0003
        Na     7.66
#       Ti     0.0018
        Zn     3.92
        P      2.7    as P
        Cl     5.0
        F      0.50
        S(6)   309    as SO4
        S(-2)  1.90   as S
        Alkalinity    122    as CaCO3
        N(-3)  0.25   as N
        N(5)   0.31   as N
        O(0)   1.20
        -water        1      #kg
```

```
        END

        SOLUTION     42     P2-11 Port 2       25-Nov-03
        temp  9.35
        pH    6.56
        pe    3.1
        redox pe
        units mg/kgw
        density      1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00004
        Ca     105.0
#       Cr
#       Cu
        Fe     0.0624
        Pb     0.0008
        Mg     43.5
        Mn     0.136
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     2.45
        P      1.1    as P
#       Cl
#       F
        S(6)   292    as SO4
        S(-2)  0.83   as S
        Alkalinity   124    as CaCO3
        N(-3)  0.33   as N
        N(5)   0.75   as N
        O(0)   0.86
        -water       1      #kg
        END

        SOLUTION     43     P2-12 Port 2       22-Dec-03
        temp  9.2
        pH    6.43
        pe    4.8
        redox pe
        units mg/kgw
        density      1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00006
        Ca     95.3
#       Cr
#       Cu
        Fe     0.0441
        Pb     0.00094
        Mg     40.6
        Mn     0.093
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
```

```
#       Ti
        Zn     2.28
        P      1.0    as P
#       Cl
#       F
        S(6)   296    as SO4
        S(-2)  1.30   as S
        Alkalinity    116   as CaCO3
        N(-3)  0.32   as N
        N(5)   1.20   as N
        O(0)   8.77
        -water        1     #kg
        END

        SOLUTION      44    P2-13 Port 2      10-Feb-04
        temp   9.27
        pH     6.43
        pe     4.7
        redox pe
        units mg/kgw
        density       1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00004
        Ca     97.6
#       Cr
#       Cu
        Fe     0.115
        Pb     0.00072
        Mg     39.4
        Mn     0.132
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     1.21
        P      1.1    as P
#       Cl
#       F
        S(6)   265    as SO4
        S(-2)  1.50   as S
        Alkalinity    119   as CaCO3
        N(-3)  0.75   as N
        N(5)   0.07   as N
        O(0)   7.93
        -water        1     #kg
        END

        SOLUTION      45    P2-14 Port 2      9-Mar-04
        temp   8.74
        pH     6.54
        pe     4.9
        redox pe
        units mg/kgw
        density       1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00009
        Ca     91.3
#       Cr
```

```
#       Cu
        Fe      0.102
        Pb      0.0012
        Mg      37.5
        Mn      0.127
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn      0.835
        P       1.0     as P
#       Cl
#       F
        S(6)    281     as SO4
        S(-2)   1.50    as S
        Alkalinity      132     as CaCO3
        N(-3)   0.08    as N
        N(5)    0.12    as N
        O(0)    0.45
        -water          1       #kg
        END

        SOLUTION        46      P2-15 Port 2        1-Apr-04
        temp    9.07
        pH      6.36
        pe      5.2
        redox pe
        units mg/kgw
        density         1
#       Al
#       Sb
#       As
#       Be
        Cd      0.00005
        Ca      99.8
#       Cr
#       Cu
        Fe      0.164
        Pb      0.0012
        Mg      41.2
        Mn      0.171
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn      0.524
        P       2.1     as P
#       Cl
#       F
        S(6)    274     as SO4
        S(-2)   1.90    as S
        Alkalinity      122     as CaCO3
        N(-3)   0.93    as N
        N(5)    0.05    as N
        O(0)    1.32
        -water          1       #kg
        END

        SOLUTION        47      P2-16 Port 2        1-May-04
        temp    9.79                    #04/29/04
```

```
      pH    5.31
      pe    4.5
      redox pe
      units mg/kgw
      density     1
#     Al
#     Sb
#     As
#     Be
      Cd    0.00006
      Ca    95.6
#     Cr
#     Cu
      Fe    0.0122
      Pb    0.00054
      Mg    40.6
      Mn    0.282
#     Hg
#     Ni
#     K
#     Se
#     Si
#     Ag
#     Na
#     Ti
      Zn    3.92
      P     0.75  as P
#     Cl
#     F
      S(6)  330   as SO4
      S(-2) 0.59  as S
      Alkalinity  116   as CaCO3
      N(-3) 0.24  as N
      N(5)  0.14  as N
      O(0)  2.68
      -water      1     #kg
      END

      SOLUTION    48    P3-9  Port 3      23-Sep-03
      temp  9.99
      pH    6.5
      pe    4.1
      redox pe
      units mg/kgw
      density     1
#     Al
#     Sb
#     As
#     Be
      Cd    0.00008
      Ca    99.5
#     Cr
#     Cu
      Fe    0.369
      Pb    0.00078
      Mg    43.0
      Mn    0.447
#     Hg
#     Ni
#     K
#     Se
#     Si
#     Ag
#     Na
#     Ti
      Zn    4.77
      P     1.5   as P
#     Cl
```

```
#       F
        S(6)  338   as SO4
        S(-2) 0.50  as S
        Alkalinity  120   as CaCO3
        N(-3) 0.27  as N
        N(5)  0.09  as N
        O(0)  4.11
        -water       1     #kg
        END

        SOLUTION     49    P3-10 Port 3      21-Oct-03
        temp  9.93
        pH    6.5
        pe    3.1
        redox pe
        units mg/kgw
        density      1
        Al    0.0356
        Sb    0.0399
        As    0.0005
        Be    0.0017
        Cd    0.00004
        Ca    103.0
        Cr    0.009
        Cu    0.0017
        Fe    0.432
        Pb    0.0014
        Mg    44.1
        Mn    0.504
        Hg    0.0001
        Ni    0.0221
        K     0.58
        Se    0.0012
        Si    7.65
        Ag    0.0003
        Na    7.74
#       Ti    0.0018
        Zn    5.82
        P     0.6   as P
        Cl    5.0
        F     0.50
        S(6)  307   as SO4
        S(-2) 1.90  as S
        Alkalinity  118   as CaCO3
        N(-3) 0.30  as N
        N(5)  0.08  as N
        O(0)  5.87
        -water       1     #kg
        END

        SOLUTION     50    P3-11 Port 3      25-Nov-03
        temp  9.47
        pH    6.56
        pe    3.1
        redox pe
        units mg/kgw
        density      1
#       Al
#       Sb
#       As
#       Be
        Cd    0.00004
        Ca    104.0
#       Cr
#       Cu
        Fe    0.0332
        Pb    0.0008
        Mg    43.4
```

```
        Mn      0.172
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn      3.65
        P       0.88   as P
#       Cl
#       F
        S(6)   284    as SO4
        S(-2) 0.50   as S
        Alkalinity  114   as CaCO3
        N(-3) 0.23   as N
        N(5)  0.27   as N
        O(0)  1.83
        -water        1      #kg
        END

        SOLUTION      51     P3-12 Port 3       22-Dec-03
        temp  9.5
        pH    6.49
        pe    4.0
        redox pe
        units mg/kgw
        density      1
#       Al
#       Sb
#       As
#       Be
        Cd      0.00006
        Ca      95.0
#       Cr
#       Cu
        Fe      0.166
        Pb      0.00094
        Mg      40.7
        Mn      0.255
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn      4.89
        P       0.64   as P
#       Cl
#       F
        S(6)   294    as SO4
        S(-2) 0.93   as S
        Alkalinity  114   as CaCO3
        N(-3) 0.16   as N
        N(5)  0.27   as N
        O(0)  4.42
        -water        1      #kg
        END

        SOLUTION      52     P3-13 Port 3       10-Feb-04
        temp  9.41
        pH    6.32
        pe    4.1
        redox pe
        units mg/kgw
```

```
        density     1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00021
        Ca     93.4
#       Cr
#       Cu
        Fe     0.278
        Pb     0.00072
        Mg     39.0
        Mn     0.347
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     5.15
        P      0.44   as P
#       Cl
#       F
        S(6)   266    as SO4
        S(-2)  0.67   as S
        Alkalinity  116    as CaCO3
        N(-3)  0.19   as N
        N(5)   0.13   as N
        O(0)   4.81
        -water      1      #kg
        END

        SOLUTION    53     P3-14 Port 3      09-Mar-04
        temp   9.45
        pH     6.44
        pe     5.1
        redox pe
        units mg/kgw
        density     1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00033
        Ca     89.6
#       Cr
#       Cu
        Fe     0.154
        Pb     0.0012
        Mg     38.4
        Mn     0.498
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     5.33
        P      0.32   as P
#       Cl
#       F
        S(6)   291    as SO4
        S(-2)  0.67   as S
        Alkalinity  118    as CaCO3
```

```
        N(-3) 0.14  as N
        N(5)  0.17  as N
        O(0)  5.11
        -water      1     #kg
        END

        SOLUTION    54    P3-15 Port 3      01-Apr-04
        temp  9.61
        pH    6.28
        pe    5.0
        redox pe
        units mg/kgw
        density     1
#       Al
#       Sb
#       As
#       Be
        Cd    0.00026
        Ca    95.6
#       Cr
#       Cu
        Fe    0.096
        Pb    0.0012
        Mg    40.4
        Mn    0.502
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn    6.07
        P     0.5   as P
#       Cl
#       F
        S(6)  289   as SO4
        S(-2) 0.50  as S
        Alkalinity  114   as CaCO3
        N(-3) 0.08  as N
        N(5)  0.05  as N
        O(0)  5.42
        -water      1     #kg
        END

        SOLUTION    55    P3-16 Port 3      01-May-04
        temp  9.77              #4/29/04
        pH    5.26
        pe    4.7
        redox pe
        units mg/kgw
        density     1
#       Al
#       Sb
#       As
#       Be
        Cd    0.00006
        Ca    97.1
#       Cr
#       Cu
        Fe    0.049
        Pb    0.00054
        Mg    41.6
        Mn    0.353
#       Hg
#       Ni
#       K
```

```
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     4.81
        P      0.56   as P
#       Cl
#       F
        S(6)   325    as SO4
        S(-2)  0.50   as S
        Alkalinity  114    as CaCO3
        N(-3)  0.18   as N
        N(5)   0.10   as N
        O(0)   2.96
        -water       1      #kg
        END

        SOLUTION     56     P4-9  Port 4       23-Sep-03
        temp   10.34
        pH     6.74
        pe     2.8
        redox pe
        units mg/kgw
        density      1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00007
        Ca     106.0
#       Cr
#       Cu
        Fe     0.0871
        Pb     0.00078
        Mg     43.2
        Mn     0.160
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     0.01
        P      2.35   as P
#       Cl
#       F
        S(6)   331    as SO4
        S(-2)  15.33  as S
        Alkalinity  136    as CaCO3
        N(-3)  1.63   as N
        N(5)   0.89   as N
        O(0)   0.33
        -water       1      #kg
        END

        SOLUTION     57     P4-10 Port 4       21-Oct-03
        temp   9.9
        pH     6.55
        pe     1.7
        redox pe
        units mg/kgw
        density      1
        Al     0.0338
        Sb     0.0399
        As     0.0005
```

```
        Be     0.0017
        Cd     0.00004
        Ca     111.0
        Cr     0.009
        Cu     0.0014
        Fe     0.106
        Pb     0.0011
        Mg     44.9
        Mn     0.161
        Hg     0.0001
        Ni     0.0221
        K      0.61
        Se     0.0012
        Si     7.81
        Ag     0.0003
        Na     7.98
#       Ti     0.0018
        Zn     0.0067
        P      2.5    as P
        Cl     5.0
        F      0.50
        S(6)   295    as SO4
        S(-2)  10.90  as S
        Alkalinity  140    as CaCO3
        N(-3)  1.50   as N
        N(5)   0.05   as N
        O(0)   0.51
        -water       1      #kg
        END

        SOLUTION     58     P4-11 Port 4       25-Nov-03
        temp   9.13
        pH     6.74
        pe     3.3
        redox pe
        units mg/kgw
        density      1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00004
        Ca     106.0
#       Cr
#       Cu
        Fe     0.0742
        Pb     0.0008
        Mg     43.3
        Mn     0.271
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     0.139
        P      1.5    as P
#       Cl
#       F
        S(6)   291    as SO4
        S(-2)  4.20   as S
        Alkalinity  124    as CaCO3
        N(-3)  0.36   as N
        N(5)   0.05   as N
        O(0)   1.10
        -water       1      #kg
```

```
        END

        SOLUTION     59     P4-12 Port 4       22-Dec-03
        temp  9.28
        pH    6.51
        pe    3.7
        redox pe
        units mg/kgw
        density     1
#       Al
#       Sb
#       As
#       Be
        Cd    0.00006
        Ca    99.9
#       Cr
#       Cu
        Fe    0.054
        Pb    0.00094
        Mg    41.2
        Mn    0.291
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn    0.866
        P     1.4   as P
#       Cl
#       F
        S(6)  292   as SO4
        S(-2) 5.10  as S
        Alkalinity  117   as CaCO3
        N(-3) 0.35  as N
        N(5)  0.61  as N
        O(0)  0.72
        -water      1     #kg
        END

        SOLUTION     60     P4-13 Port 4       10-Feb-04
        temp  9.09
        pH    6.49
        pe    3.8
        redox pe
        units mg/kgw
        density     1
#       Al
#       Sb
#       As
#       Be
        Cd    0.00004
        Ca    96.5
#       Cr
#       Cu
        Fe    0.0528
        Pb    0.00072
        Mg    39.0
        Mn    0.229
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
```

```
#       Ti
        Zn      1.28
        P       1.2     as P
#       Cl
#       F
        S(6)    272     as SO4
        S(-2)   0.87    as S
        Alkalinity      122     as CaCO3
        N(-3)   0.36    as N
        N(5)    0.13    as N
        O(0)    0.74
        -water          1       #kg
        END

        SOLUTION        61      P4-14 Port 4        9-Mar-04
        temp    9.11
        pH      6.56
        pe      5.1
        redox pe
        units mg/kgw
        density         1
#       Al
#       Sb
#       As
#       Be
        Cd      0.00013
        Ca      92.0
#       Cr
#       Cu
        Fe      0.0524
        Pb      0.0012
        Mg      37.7
        Mn      0.187
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn      1.04
        P       1.5     as P
#       Cl
#       F
        S(6)    287     as SO4
        S(-2)   0.87    as S
        Alkalinity      126     as CaCO3
        N(-3)   0.44    as N
        N(5)    0.17    as N
        O(0)    1.18
        -water          1       #kg
        END

        SOLUTION        62      P4-15 Port 4        1-Apr-04
        temp    9.39
        pH      6.21
        pe      5.4
        redox pe
        units mg/kgw
        density         1
#       Al
#       Sb
#       As
#       Be
        Cd      0.00005
        Ca      97.8
#       Cr
```

```
#       Cu
        Fe     0.0595
        Pb     0.0012
        Mg     40.4
        Mn     0.191
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     1.31
        P      2.3    as P
#       Cl
#       F
        S(6)   281    as SO4
        S(-2)  0.93   as S
        Alkalinity  120    as CaCO3
        N(-3)  0.47   as N
        N(5)   0.11   as N
        O(0)   0.43
        -water        1      #kg
        END

        SOLUTION      63     P4-16 Port 4       1-May-04
        temp   9.81                 #4/29/04
        pH     5.46
        pe     4.6
        redox pe
        units mg/kgw
        density       1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00006
        Ca     99.0
#       Cr
#       Cu
        Fe     0.138
        Pb     0.00054
        Mg     41.4
        Mn     0.25
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     1.59
        P      1.3    as P
#       Cl
#       F
        S(6)   321    as SO4
        S(-2)  0.50   as S
        Alkalinity  120    as CaCO3
        N(-3)  0.60   as N
        N(5)   0.09   as N
        O(0)   2.12
        -water        1      #kg
        END

#       DATA ADDED FOR OCTOBER 2004 REPORT
```

```
        SOLUTION     1      P1-17 Port 1       25-May-04
        temp  9.98
        pH    5.83
        pe    3.8
        redox pe
        units mg/kgw
        density      1
#       Al
#       Sb
#       As
#       Be
        Cd    0.00048
        Ca    85.4
#       Cr
#       Cu
        Fe    0.27
        Pb    0.0007
        Mg    38.2
        Mn    0.50
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn    7.03
        P     0.3    as P
#       Cl
#       F
        S(6)  319    as SO4
        S(-2) 0.50   as S
        Alkalinity   113    as CaCO3
        N(-3) 0.12   as N
        N(5)  0.05   as N
        O(0)  6.47
        -water       1      #kg
        END

        SOLUTION     1      P1-18 Port 1       22-Jun-04
        temp  10.07
        pH    6.83
        pe    5.4
        redox pe
        units mg/kgw
        density      1
#       Al
#       Sb
#       As
#       Be
        Cd    0.00052
        Ca    92.1
#       Cr
#       Cu
        Fe    0.31
        Pb    0.0005
        Mg    42.0
        Mn    0.61
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
```

```
        Zn     7.32
        P      0.1    as P
#       Cl
#       F
        S(6)   344    as SO4
        S(-2)  0.05   as S
        Alkalinity    113    as CaCO3
        N(-3)  0.05   as N
        N(5)   0.48   as N
        O(0)   5.95
        -water        1      #kg
        END

        SOLUTION      1      P1-19 Port 1       26-Jul-04
        temp   10.12
        pH     6.76
        pe     4.5
        redox pe
        units mg/kgw
        density       1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00052
        Ca     97.8
#       Cr
#       Cu
        Fe     0.74
        Pb     0.0012
        Mg     43.2
        Mn     0.60
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     7.49
        P      0.1    as P
#       Cl
#       F
        S(6)   349    as SO4
        S(-2)  0.05   as S
        Alkalinity    118    as CaCO3
        N(-3)  0.12   as N
        N(5)   0.05   as N
        O(0)   7.40
        -water        1      #kg
        END

        SOLUTION      1      P1-20 Port 1       17-Aug-04
        temp   10.11
        pH     6.55
        pe     5.1
        redox pe
        units mg/kgw
        density       1
        Al     0.0264
        Sb     0.0017
        As     0.0011
        Be     0.0001
        Cd     0.00048
        Ca     103.0
        Cr     0.010
        Cu     0.0016
```

```
        Fe     0.50
        Pb     0.0012
        Mg     45.1
        Mn     0.61
        Hg     0.0001
        Ni     0.0175
        K      0.59
        Se     0.0008
        Si     7.78
        Ag     0.0023
        Na     7.81
#       Ti
        Zn     8.00
        P      0.1    as P
        Cl     5.0
        F      0.50
        S(6)   349    as SO4
        S(-2)  0.50   as S
        Alkalinity    118    as CaCO3
        N(-3)  0.05   as N
        N(5)   0.05   as N
        O(0)   6.85
        -water        1      #kg
        END

        SOLUTION      1      P2-17 Port 2       25-May-04
        temp   9.92
        pH     5.77
        pe     3.8
        redox pe
        units mg/kgw
        density       1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00010
        Ca     93.4
#       Cr
#       Cu
        Fe     0.04
        Pb     0.0007
        Mg     41.2
        Mn     0.18
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     4.98
        P      0.4    as P
#       Cl
#       F
        S(6)   330    as SO4
        S(-2)  0.50   as S
        Alkalinity    113    as CaCO3
        N(-3)  0.14   as N
        N(5)   0.30   as N
        O(0)   3.06
        -water        1      #kg
        END

        SOLUTION      1      P2-18 Port 2       22-Jun-04
        temp   10.23
        pH     6.69
```

```
        pe    5.9
        redox pe
        units mg/kgw
        density     1
  #     Al
  #     Sb
  #     As
  #     Be
        Cd    0.00006
        Ca    91.9
  #     Cr
  #     Cu
        Fe    0.02
        Pb    0.0005
        Mg    41.7
        Mn    0.08
  #     Hg
  #     Ni
  #     K
  #     Se
  #     Si
  #     Ag
  #     Na
  #     Ti
        Zn    3.09
        P     0.9   as P
  #     Cl
  #     F
        S(6)  337   as SO4
        S(-2) 0.05  as S
        Alkalinity  117   as CaCO3
        N(-3) 0.71  as N
        N(5)  0.11  as N
        O(0)  0.46
        -water      1     #kg
        END

        SOLUTION    1     P2-19 Port 2      26-Jul-04
        temp  10.58
        pH    6.66
        pe    4.5
        redox pe
        units mg/kgw
        density     1
  #     Al
  #     Sb
  #     As
  #     Be
        Cd    0.00003
        Ca    100.0
  #     Cr
  #     Cu
        Fe    0.09
        Pb    0.0012
        Mg    43.2
        Mn    0.09
  #     Hg
  #     Ni
  #     K
  #     Se
  #     Si
  #     Ag
  #     Na
  #     Ti
        Zn    3.03
        P     1.0   as P
  #     Cl
  #     F
```

```
        S(6)  342    as SO4
        S(-2) 0.05   as S
        Alkalinity  125   as CaCO3
        N(-3) 0.89   as N
        N(5)  0.05   as N
        O(0)  0.17
        -water       1      #kg
        END

        SOLUTION     1      P2-20 Port 2      17-Aug-04
        temp  10.46
        pH    6.66
        pe    4.3
        redox pe
        units mg/kgw
        density      1
        Al    0.0264
        Sb    0.0034
        As    0.0008
        Be    0.0001
        Cd    0.00003
        Ca    105.0
        Cr    0.010
        Cu    0.0016
        Fe    0.03
        Pb    0.0012
        Mg    44.7
        Mn    0.07
        Hg    0.0001
        Ni    0.0213
        K     0.59
        Se    0.0008
        Si    7.65
        Ag    0.0023
        Na    7.87
#       Ti
        Zn    3.70
        P     0.9    as P
        Cl    5.0
        F     0.50
        S(6)  351    as SO4
        S(-2) 0.95   as S
        Alkalinity  126   as CaCO3
        N(-3) 0.44   as N
        N(5)  0.28   as N
        O(0)  0.13
        -water       1      #kg
        END

        SOLUTION     1      P3-17 Port 3      25-May-04
        temp  9.9
        pH    5.76
        pe    3.6
        redox pe
        units mg/kgw
        density      1
#       Al
#       Sb
#       As
#       Be
        Cd    0.00019
        Ca    94.2
#       Cr
#       Cu
        Fe    0.10
        Pb    0.0007
        Mg    41.9
        Mn    0.26
```

```
#     Hg
#     Ni
#     K
#     Se
#     Si
#     Ag
#     Na
#     Ti
      Zn    5.59
      P     0.3   as P
#     Cl
#     F
      S(6)  324   as SO4
      S(-2) 0.50  as S
      Alkalinity  116   as CaCO3
      N(-3) 0.11  as N
      N(5)  0.17  as N
      O(0)  5.36
      -water      1     #kg
      END

      SOLUTION    1     P3-18 Port 3      22-Jun-04
      temp  10.21
      pH    6.66
      pe    3.2
      redox pe
      units mg/kgw
      density     1
#     Al
#     Sb
#     As
#     Be
      Cd    0.00006
      Ca    93.5
#     Cr
#     Cu
      Fe    0.09
      Pb    0.0005
      Mg    42.8
      Mn    0.09
#     Hg
#     Ni
#     K
#     Se
#     Si
#     Ag
#     Na
#     Ti
      Zn    2.50
      P     1.3   as P
#     Cl
#     F
      S(6)  337   as SO4
      S(-2) 0.50  as S
      Alkalinity  123   as CaCO3
      N(-3) 0.79  as N
      N(5)  0.05  as N
      O(0)  0.19
      -water      1     #kg
      END

      SOLUTION    1     P3-19 Port 3      26-Jul-04
      temp  10.62
      pH    6.67
      pe    2.8
      redox pe
      units mg/kgw
      density     1
```

```
#      Al
#      Sb
#      As
#      Be
       Cd     0.00003
       Ca     101.0
#      Cr
#      Cu
       Fe     0.34
       Pb     0.0012
       Mg     43.5
       Mn     0.11
#      Hg
#      Ni
#      K
#      Se
#      Si
#      Ag
#      Na
#      Ti
       Zn     2.56
       P      1.1    as P
#      Cl
#      F
       S(6)   344    as SO4
       S(-2)  0.05   as S
       Alkalinity  124    as CaCO3
       N(-3)  1.00   as N
       N(5)   0.05   as N
       O(0)   0.19
       -water        1      #kg
       END

       SOLUTION      1      P3-20 Port 3       17-Aug-04
       temp   10.64
       pH     6.54
       pe     4.5
       redox  pe
       units  mg/kgw
       density       1
       Al     0.0264
       Sb     0.0036
       As     0.0010
       Be     0.0001
       Cd     0.00003
       Ca     105.0
       Cr     0.010
       Cu     0.0016
       Fe     0.11
       Pb     0.0012
       Mg     45.5
       Mn     0.18
       Hg     0.0001
       Ni     0.0175
       K      0.59
       Se     0.0008
       Si     7.76
       Ag     0.0023
       Na     7.88
#      Ti
       Zn     4.40
       P      0.7    as P
       Cl     5.0
       F      0.50
       S(6)   349    as SO4
       S(-2)  0.59   as S
       Alkalinity  127    as CaCO3
       N(-3)  0.44   as N
```

```
        N(5)  0.10  as N
        O(0)  2.44
        -water      1     #kg
        END

        SOLUTION    1     P4-17 Port 4      25-May-04
        temp  10.13
        pH    6.29
        pe    2.8
        redox pe
        units mg/kgw
        density     1
#       Al
#       Sb
#       As
#       Be
        Cd    0.00005
        Ca    96.8
#       Cr
#       Cu
        Fe    0.16
        Pb    0.0007
        Mg    41.4
        Mn    0.17
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn    0.88
        P     1.3   as P
#       Cl
#       F
        S(6)  316   as SO4
        S(-2) 1.50  as S
        Alkalinity  125   as CaCO3
        N(-3) 1.10  as N
        N(5)  0.30  as N
        O(0)  1.82
        -water      1     #kg
        END

        SOLUTION    1     P4-18 Port 4      22-Jun-04
        temp  10.31
        pH    6.77
        pe    0.4
        redox pe
        units mg/kgw
        density     1
#       Al
#       Sb
#       As
#       Be
        Cd    0.00006
        Ca    91.5
#       Cr
#       Cu
        Fe    0.33
        Pb    0.0005
        Mg    41.9
        Mn    0.18
#       Hg
#       Ni
#       K
#       Se
```

```
#     Si
#     Ag
#     Na
#     Ti
      Zn    0.01
      P     1.0    as P
#     Cl
#     F
      S(6)  318    as SO4
      S(-2) 2.50   as S
      Alkalinity   144   as CaCO3
      N(-3) 2.40   as N
      N(5)  0.05   as N
      O(0)  0.21
      -water       1     #kg
      END

      SOLUTION     1     P4-19 Port 4      26-Jul-04
      temp  11.38
      pH    6.72
      pe    1.5
      redox pe
      units mg/kgw
      density      1
#     Al
#     Sb
#     As
#     Be
      Cd    0.00005
      Ca    100.0
#     Cr
#     Cu
      Fe    0.23
      Pb    0.0012
      Mg    42.9
      Mn    0.17
#     Hg
#     Ni
#     K
#     Se
#     Si
#     Ag
#     Na
#     Ti
      Zn    0.04
      P     2.7    as P
#     Cl
#     F
      S(6)  313    as SO4
      S(-2) 8.20   as S
      Alkalinity   154   as CaCO3
      N(-3) 3.50   as N
      N(5)  0.05   as N
      O(0)  0.24
      -water       1     #kg
      END

      SOLUTION     1     P4-20 Port 4      17-Aug-04
      temp  11.67
      pH    6.72
      pe    0.8
      redox pe
      units mg/kgw
      density      1
      Al    0.0264
      Sb    0.0022
      As    0.0007
      Be    0.0001
```

```
        Cd     0.00003
        Ca     105.0
        Cr     0.010
        Cu     0.0016
        Fe     0.16
        Pb     0.0012
        Mg     44.9
        Mn     0.16
        Hg     0.0001
        Ni     0.0199
        K      0.60
        Se     0.0008
        Si     7.79
        Ag     0.0023
        Na     7.92
#       Ti
        Zn     0.01
        P      4.4    as P
        Cl     5.0
        F      0.50
        S(6)   315    as SO4
        S(-2)  8.60   as S
        Alkalinity  149    as CaCO3
        N(-3)  7.80   as N
        N(5)   1.70   as N
        O(0)   0.24
        -water        1      #kg
        END
```

```
    SELECTED_OUTPUT
    -file         MSEApril.out
    -percent_error
    -ionic strengh
    -alkalinity
    -saturation_indices Calcite  Dolomite Gypsum
    otavite     Greenockite  Cd(OH)2(A)  CdSO4  CdSO4:H2O
    Cd3(PO4)2
    Fluorite
    Ferrihydrite  Siderite  Melanterite FeS(ppt) pyrite
    CO2(g)  O2(g)
    Magnesite  Epsomite
    Birnessite  Rhodochrosite  Manganite
    Mn3(PO4)2  MnHPO4(C)
    Anglesite  Cerrusite Galena  Hydcerrusite
    ClPyromorphite  Hxypyromorphite  Pb3(PO4)2  PbHPO4
    hydroxyapatite  vivianite  FCO3Apatite  Strengite
    SiO2(a)
    Smithsonite  Sphalerite  Wurtzite  Zn(OH)2(G)  Goslarite
    Zn3(PO4)2:4H2O
    Jarosite-K  Jarosite-Na  Jarosite-H
    Al(OH)3(a)  Al4(OH)10SO4  AlOHSO4  Gibbsite(c)  Boehmite
    Millerite  Ni(OH)2

    -equilibrium_phases  Calcite  Dolomite Gypsum
    otavite     Greenockite  Cd(OH)2(A)  CdSO4  CdSO4:H2O
    Cd3(PO4)2
    Fluorite
    Ferrihydrite  Siderite  Melanterite FeS(ppt) pyrite
    CO2(g)  O2(g)
    Magnesite  Epsomite
    Birnessite  Rhodochrosite  Manganite
    Mn3(PO4)2  MnHPO4(C)
    Anglesite  Cerrusite Galena  Hydcerrusite
    ClPyromorphite  Hxypyromorphite  Pb3(PO4)2  PbHPO4
    hydroxyapatite  vivianite  FCO3Apatite  Strengite
    SiO2(a)
    Smithsonite  Sphalerite  Wurtzite  Zn(OH)2(G)  Goslarite
    Zn3(PO4)2:4H2O
    Jarosite-K  Jarosite-Na  Jarosite-H
    Al(OH)3(a)  Al4(OH)10SO4  AlOHSO4  Gibbsite(c)  Boehmite
    Millerite  Ni(OH)2

    -totals  Cd  Ca  Fe  Pb  Mg  Mn  Na Zn  P  S(6)  S(-2)  N(-3)  N(5) N(3) N


    PHASES
    C102H151O39N31
    C102H151O39N31+267H2O = 102CO3-2 + 31 NH3 + 592 H+ + 388 e-
    -log_K 0.0


    SOLUTION     5      P1-4  Port 1      23-Apr-03
    temp  9.98
    pH    6.73
    pe    3.4
    redox pe
    units mg/kgw
    density     1
#   Al
#   Sb
#   As
#   Be
    Cd    0.00053
    Ca    82.7
#   Cr
#   Cu
    Fe    0.52
```

```
        Pb     0.0006
        Mg     38.5
        Mn     0.65
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
        Na     0.01   charge
#       Ti
        Zn     5.52
        P      0.1    as P
#       Cl
#       F
        S(6)   284    as SO4
        S(-2)  0.05   as S
        Alkalinity    116    as CaCO3
        N(-3)  0.05   as N
        N(5)   0.08   as N
#       O(0)
        -water        1      #kg
        END


        SOLUTION      8      P2-4  Port 2       23-Apr-03
        temp   9.83
        pH     6.72
        pe     2.1
        redox pe
        units mg/kgw
        density       1
#       Al
#       Sb
#       As
#       Be
        Cd     0.00005
        Ca     89.8
#       Cr
#       Cu
        Fe     0.01
        Pb     0.0007
        Mg     39.8
        Mn     0.40
#       Hg
#       Ni
#       K
#       Se
#       Si
#       Ag
#       Na
#       Ti
        Zn     0.01
        P      1.2    as P
#       Cl
#       F
        S(6)   273    as SO4
        S(-2)  1.60   as S
        Alkalinity    112    as CaCO3
        N(-3)  0.68   as N
        N(5)   1.10   as N
#       O(0)
        -water        1      #kg
        END

        SOLUTION      11     P3-4  Port 3       23-Apr-03
        temp   9.85
```

```
      pH    6.72
      pe    2.7
      redox pe
      units mg/kgw
      density     1
#     Al
#     Sb
#     As
#     Be
      Cd    0.00005
      Ca    87.9
#     Cr
#     Cu
      Fe    0.22
      Pb    0.0006
      Mg    39.7
      Mn    0.56
#     Hg
#     Ni
#     K
#     Se
#     Si
#     Ag
#     Na
#     Ti
      Zn    4.08
      P     0.4   as P
#     Cl
#     F
      S(6)  274   as SO4
      S(-2) 1.40  as S
      Alkalinity  117   as CaCO3
      N(-3) 0.43  as N
      N(5)  0.70  as N
#     O(0)
      -water      1     #kg
      END


      SOLUTION    14    P4-4  Port 4      23-Apr-03
      temp  9.73
      pH    6.92
      pe    1.2
      redox pe
      units mg/kgw
      density     1
#     Al
#     Sb
#     As
#     Be
      Cd    0.00005
      Ca    93.0
#     Cr
#     Cu
      Fe    0.07
      Pb    0.0009
      Mg    39.4
      Mn    0.21
#     Hg
#     Ni
#     K
#     Se
#     Si
#     Ag
#     Na
#     Ti
      Zn    0.01
      P     2.4   as P
```

```
#     Cl
#     F
      S(6)  259   as SO4
      S(-2) 14.00 as S
      Alkalinity  142   as CaCO3
      N(-3) 1.50  as N
      N(5)  0.89  as N
#     O(0)
      -water      1     #kg
      END

      USE SOLUTION      5

      EQUILIBRIUM_PHASES 5
      ferrihydrite      0     0

      SURFACE     5
      Hfo_w   ferrihydrite   0.2   600
      Hfo_s  ferrihydrite   0.005

      SAVE SOLUTION     6
      END

      USE SOLUTION      6

      EQUILIBRIUM_PHASES 6
      hydroxyapatite    0     10
      MnHPO4(c)   0     0
      Calcite     0     0
      Gypsum      0     0
      Ferrihydrite      0     0
#     FeS(ppt)    0     0
#     pyrite      0     0
      galena      0     0
      sphalerite  0     0
      wurtzite    0     0
      Greenockite             0     0

      REACTION
      C102H151O39N31    0.0000039

      SAVE SOLUTION     7
      END

      USE SOLUTION      6

      EQUILIBRIUM_PHASES 6
      hydroxyapatite    0     10
      MnHPO4(c)   0     0
      Calcite     0     0
      Gypsum      0     0
      Ferrihydrite      0     0
#     FeS(ppt)    0     0
#     pyrite      0     0
      galena      0     0
      sphalerite  0     0
      wurtzite    0     0
      Greenockite             0     0

      REACTION
      C102H151O39N31    0.00000281

      SAVE SOLUTION     8
      END

      USE SOLUTION      6

      EQUILIBRIUM_PHASES 6
```

```
      hydroxyapatite     0     10
      MnHPO4(c)    0     0
      Calcite      0     0
      Gypsum       0     0
      Ferrihydrite       0     0
#     FeS(ppt)     0     0
#     pyrite       0     0
      galena       0     0
      sphalerite   0     0
      wurtzite     0     0
      Greenockite              0     0

      REACTION
      C102H151O39N31    0.00000548

      SAVE SOLUTION      9
      END
```

Appendix E

Solid Phase Digestion Results

App E
(go to worksheet named
"Appendix --- Data for
Graphs")

MWTP, P39, Long-Term Monitoring of a Permeable Treatment Wall

Apatite II (fishbone) Material Used in the Apatite Treatment System

Fish Bone Digestion Data

Sample Location and Date	Untreated Fishbone Bucket 1	Untreated Fishbone Bucket 2	Untreated Fishbone Bucket 3	Tank 2 (SP2) - 7/03 - Surface	Tank 2 (SP2) - 7/03 - 8" Depth	Tank 2 (SP2) - 7/03 - 16" Depth	Tank 2 (SP2) - 7/03 - 24" Depth	Tank 2 (SP2) - 7/03 - 32" Depth	Tank 2 (SP2) - 9/04 - Surface	Tank 2 (SP2) - 9/04 - 8" Depth	Tank 2 (SP2) - 9/04 - 16" Depth	Tank 2 (SP2) - 9/04 - 24" Depth	Tank 2 (SP2) - 9/04 - 32" Depth
Ca	201107	197926	212765	214092	172946	230627	205466	174077	37000	119000	105000	153000	137000
Cd	0.23	0.23	0.25	1.19	0.89	0.09	0.77	0.66	10.3	3.82	3.85	2.73	2.15
Fe	219	119	168	3225	3449	1909	1913	2204	26600	3820	5470	1670	2270
Mg	3173	3214	3114	2755	2657	2555	2516	2194	525	1160	1370	1370	1270
Mn	17.25	15.74	41.22	592	656	513	455	587	10400	1360	2160	508	720
Pb	0.46	0.47	0.48	4.61	8.07	2.97	2.32	5.09	42.4	5.65	12.1	2.18	2.94
Zn	168	121	149	14092	14685	15221	12912	13907	16400	22000	17900	15000	21500

Sample Location and Date	Untreated Fishbone Bucket 1	Untreated Fishbone Bucket 2	Untreated Fishbone Bucket 3	Tank 3 (SP3) - 7/03 - Surface	Tank 3 (SP3) - 7/03 - 8" Depth	Tank 3 (SP3) - 7/03 - 16" Depth	Tank 3 (SP3) - 7/03 - 24" Depth	Tank 3 (SP3) - 7/03 - 32" Depth	Tank 3 (SP3) - 9/04 - Surface	Tank 3 (SP3) - 9/04 - 8" Depth	Tank 3 (SP3) - 9/04 - 16" Depth	Tank 3 (SP3) - 9/04 - 24" Depth	Tank 3 (SP3) - 9/04 - 32" Depth
Ca	201107	197926	212765	205544	217092	229167	230920	219378	107000	141000	149000	110000	123000
Cd	0.23	0.23	0.25	1.76	2.33	0.99	1.14	1.28	4.16	3.59	2.07	1.39	2.65
Fe	219	119	168	5249	8831	3002	2808	3647	9940	2420	2690	2410	3150
Mg	3173	3214	3114	2275	2593	2481	2397	2550	981	1360	1440	993	1080
Mn	17.25	15.74	41.22	1415	1886	945	789	878	4770	779	980	739	961
Pb	0.46	0.47	0.48	7.02	21.51	3.89	4.01	13.89	16.7	4.36	3.97	3.61	5.19
Zn	168	121	149	18356	18566	13826	17417	18007	20000	18100	15200	23100	25600

Sample Location and Date	Untreated Fishbone Bucket 1	Untreated Fishbone Bucket 2	Untreated Fishbone Bucket 3	Tank 4 (SP4) - 7/03 - Surface	Tank 4 (SP4) - 7/03 - 8" Depth	Tank 4 (SP4) - 7/03 - 16" Depth	Tank 4 (SP4) - 7/03 - 24" Depth	Tank 4 (SP4) - 7/03 - 32" Depth	Tank 4 (SP4) - 9/04 - Surface	Tank 4 (SP4) - 9/04 - 8" Depth	Tank 4 (SP4) - 9/04 - 16" Depth	Tank 4 (SP4) - 9/04 - 24" Depth	Tank 4 (SP4) - 9/04 - 32" Depth
Ca	201107	197926	212765	219178	221477	178399	209961	224122	104000	106000	119000	139000	120000
Cd	0.23	0.23	0.25	0.85	0.64	0.32	0.53	0.35	1.89	1.56	1.79	0.93	0.78
Fe	219	119	168	3268	2013	1764	2861	1329	6150	4890	5060	3210	3240
Mg	3173	3214	3114	26112	2617	2314	2588	2640	1080	1310	1250	1470	1400
Mn	17.25	15.74	41.22	675	530	412	724	384	1830	1280	1180	708	1100
Pb	0.46	0.47	0.48	10.08	3.12	1.62	2.71	0.53	12.1	10.6	12.5	5.74	18.6
Zn	168	121	149	13699	11505	7396	14063	7996	24300	21500	23800	21900	18500

Appendix F

EPA Statistical Analysis

STATISTICAL SUPPORT FOR RESEARCH ACTIVITIES

GENERAL INFORMATION

QA ID No.:	**N/A**	Project QA Category:	**N/A**
EPA Technical Lead Person (TLP):		**Norma Lewis**	
Title:		**Data Analysis Guidance for MWTP Activity III, Project 39: Nevada Stewart Site**	
Support Provided by:		**Neptune & Co.**	
Contract No.	**68-C-03-032**	Date Submitted:	**09/24/04**

REVIEW SUMMARY

Review Distribution Date	11/01/04	Endorsement Status	**N/A**
NRMRL-STD QA Manager	Lauren Drees	No. of Findings	**N/A**
Telephone No.	569-7087	No. of Observations	**N/A**

The project objectives, design information, and data which was provided to EPA for the above project have been reviewed by a statistician. Representative target analytes have been evaluated. Guidance is attached with respect to the data analyses to be performed.

If you have any questions or need additional information, please contact the STD QA Manager.

cc: Diana Bless
Helen Joyce
Lynn McCloskey

Note: Data analyses (both descriptive and inferential) have been performed for Cd. Pb, and Zn. This information is summarized as listed below:

- Descriptive Statistics: Minimum, Medium, Maximum, Mean, Standard Deviation (Page 3)
- Inferential Statistics: Kruskal-Wallis Test and Multiple Comparison Procedure (Pages 4 and 5)
- Graphical Displays: Box Plots (Pages 6 - 8)
- Graphical Displays: Time Plots (Pages 9 - 11)
- Appendix A: How to Interpret Box Plots (Page 12)

Disclaimer: This is one application of three technologies, referred to as SP2, SP3, and SP4. Since there are no replications, this investigation provides no information on how these technologies would perform at other locations. Any inferences from these data are valid for this site only.

Exploratory Data Analysis

The percent reduction for the three metals was used to construct the box plots on pages 6 - 8. Percent reduction was calculated as [(SP 1 Metal Conc. - SP # Metal Conc.) / SP 1 Metal Conc.] x 100. The box plots for Cd (page 6) and Pb (page 7) display an outlier from the same sampling event, 8/19/03 and sampling port, 2. (An outlier is defined as a value that is outside the main body of the data.) In each case, there is an approximate 200% increase in the metal concentration. The box plots for Zn display an outlier on 02/26/03 for sampling port 4. Since there is no assignable cause for these outlying values, all analyses were done with and without the outliers.

The cadmium box plots (Figure 1, page 6) show a high (> 75%) reduction for sampling ports 2 and 4. The time plots in Figure 4 (page 9) indicate this reduction is independent of the influent concentration ($r = -0.29$ for SP2 vs. SP1 and $r = -0.07$ for SP4 vs. SP1). This does not hold for sampling port 3, where the reduction is a function of the influent concentration ($r = 0.67$ for SP3 vs. SP1). This is seen in Figure 4 where the time plot lines for sampling ports 1 and 3 are similar and in Figure 1 where the height of the box plot for sampling port 3 is larger than the heights for the box plots for sampling ports 2 and 4. These observations are confirmed with the Kruskal-Wallis test. The result of the Kruskal-Wallis test (page 4) is statistically significant (p-value = 0.0002). (The null hypothesis is that the true location parameter for the groups is the same and the alternative hypothesis is that there is difference in at least one of the groups.) The Kruskal-Wallis multiple comparison procedure indicates that sampling ports 2 and 4 are statistically different from sampling port 3 (p-value = 0.05). The inferential results are similar whether or not the outlier is included.

The Pb box plots (Figure 2, page 7) show a similar reduction for all three sampling ports (20% -

80%). The time plots in Figure 5 (page 10) indicate this reduction is independent of the influent concentration for sampling ports 2 and 4 ($r = 0.05$ for SP2 vs. SP1 and $r = 0.18$ for SP4 vs. SP1). This does not hold for sampling port 3, where the reduction is a function of high influent concentrations ($r = 0.89$ for SP3 vs. SP1). This is seen in Figure 5 where the time plot lines for sampling ports 1 and 3 are similar. The result of the Kruskal-Wallis test (pages 4 and 5) is statistically significant (p-value = 0.0002) when the outlier is removed. The Kruskal-Wallis multiple comparison procedure indicates that sampling ports 2 and 3 are statistically different (p-value = 0.05). The result of the Kruskal-Wallis test is not statistically significant (p-value = 0.0694) with the outlier included.

The Zn box plots (Figure 3, page 8) show a high (> 80%) reduction for sampling port 4. The time plot in Figure 6 (page 11) indicates this reduction is independent of the influent concentration ($r = 0.05$ for SP4 vs. SP1). Sampling ports 2 and 3 show more modest reductions, 20% - 70%, where the reduction is a function of the influent concentration ($r = 0.63$ for SP2 vs. SP1 and $r = 0.38$ for SP3 vs. SP1). The result of the Kruskal-Wallis test is statistically significant (p-value = 0.0002). The Kruskal-Wallis multiple comparison procedure indicates that all sampling ports are statistically different from one another (p-value = 0.05). The inferential results are similar whether or not the outlier is included.

Table 1. Cd Percent Reduction for Selected Metals by Sampling Port

Port	Min.	Medium	Mean	Maximum	Std. Dev.
SP2	-198.1	89.6	75.1	97.3	66.3
SP2*	82.5	89.9	90.3	97.3	3.7
SP3	-22.1	63.0	57.9	81.6	31.8
SP4	61.4	89.6	88.1	97.3	7.9

*Outlier removed SP2 08/19/2003

Table 2. Pb Percent Reduction for Selected Metals by Sampling Port

Port	Min.	Medium	Mean	Maximum	Std. Dev.
SP2	-214.8	54.2	39.1	94.6	67.0
SP2*	0	54.6	53.2	75.3	27.5
SP3	-8.4	37.8	35.0	77.5	26.3
SP4	0	52.0	75.5	94.6	29.6

*Outlier Removed SP2 08/19/2003

Table 3. Zn Percent Reduction for Selected Metals by Sampling Port

Port	Min.	Medium	Mean	Maximum	Std. Dev.
SP2	29.2	58.9	58.4	86.1	15.0
SP3	13.6	34.1	38.6	87.8	20.9
SP4	8.4	93.3	85.9	99.8	20.8
SP4*	72.2	94.1	90.0	99.8	10.3

*Outlier removed Zn 02/26/2003

Table 4. Kruskal-Wallis Test and Multiple Comparison Procedure for Cd

Kruskal-Wallis Test: chi-square = 17.0977, df = 2, p-value = 0.0002			
Multiple Comparison	**Difference***	**Statistic**	**S/NS ($\alpha = 0.05$)**
SP2 versus SP3	19.66	9.16	S
SP2 versus SP4	0.79	9.16	NS
SP3 versus SP4	18.87	9.16	S

*If the difference > statistic, then statistically significant at the 0.05 level.

Table 5. Kruskal-Wallis Test and Multiple Comparison Procedure for Cd Outlier Removed

Kruskal-Wallis Test: chi-square = 19.521, df = 2, p-value = 0.0001			
Multiple Comparison	**Difference***	**Statistic**	**S/NS ($\alpha = 0.05$)**
SP2 versus SP3	21.59	8.80	S
SP2 versus SP4	2.72	8.80	NS
SP3 versus SP4	18.87	8.80	S

*If the difference > statistic, then statistically significant at the 0.05 level.

Table 6. Kruskal-Wallis Test and Multiple Comparison Procedure for Pb

Kruskal-Wallis Test: chi-square = 4.3512, df = 2, p-value = 0.1135			
Multiple Comparison	**Difference***	**Statistic**	**S/NS ($\alpha = 0.05$)**
SP2 versus SP3	9.53	10.55	NS
SP2 versus SP4	0.37	10.55	NS
SP3 versus SP4	9.89	10.55	NS

*If the difference > statistic, then statistically significant at the 0.05 level.

Table 7. Kruskal-Wallis Test and Multiple Comparison Procedure for Pb Outlier Removed

Kruskal-Wallis Test: chi-square = 5.3359, df = 2, p-value = 0.0694			
Multiple Comparison	**Difference***	**Statistic**	**S/NS ($\alpha = 0.05$)**
SP2 versus SP3	11.25	10.40	S
SP2 versus SP4	1.36	10.40	NS
SP3 versus SP4	9.89	10.26	NS

*If the difference > statistic, then statistically significant at the 0.05 level.

Table 8. Kruskal-Wallis Test and Multiple Comparison Procedure for Zn

Kruskal-Wallis Test: chi-square = 32.4289, df = 2, p-value = 0.0002			
Multiple Comparison	**Difference***	**Statistic**	**S/NS ($\alpha = 0.05$)**
SP2 versus SP3	11.50	7.55	S
SP2 versus SP4	19.60	7.55	S
SP3 versus SP4	31.10	7.55	S

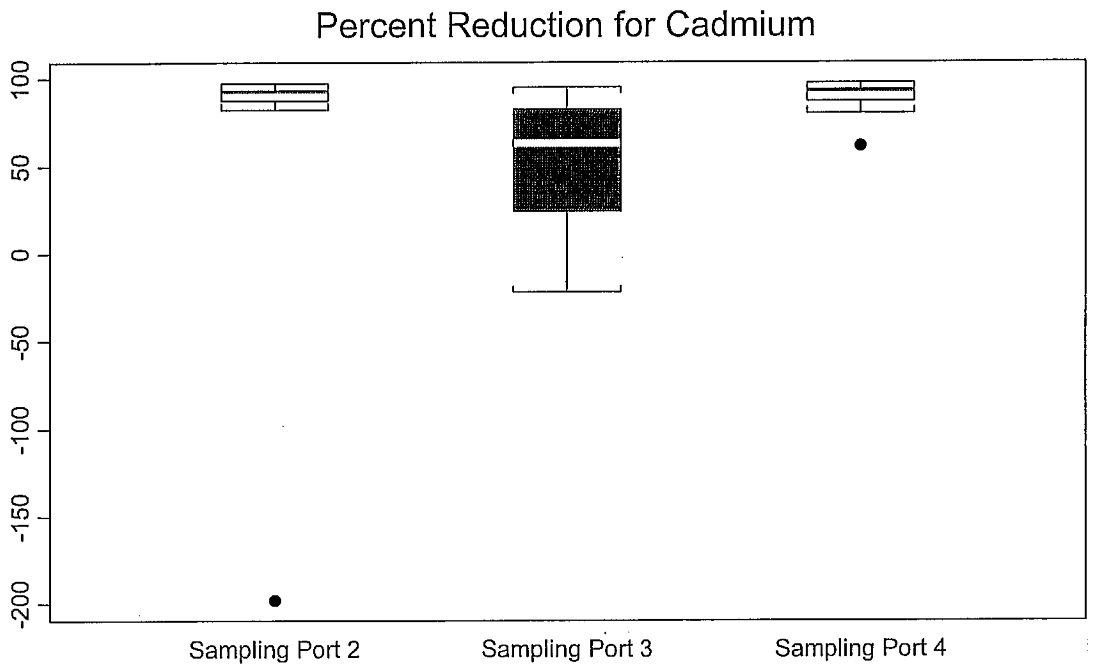
*If the difference > statistic, then statistically significant at the 0.05 level.

Table 9. Kruskal-Wallis Test and Multiple Comparison Procedure for Zn Outlier Removed

Kruskal-Wallis Test: chi-square = 38.2104, df = 2, p-value = 0.0001			
Multiple Comparison	**Difference***	**Statistic**	**S/NS ($\alpha = 0.05$)**
SP2 versus SP3	11.50	7.35	S
SP2 versus SP4	22.04	7.35	S
SP3 versus SP4	33.54	7.45	S

*If the difference > statistic, then statistically significant at the 0.05 level.

Figure 1. Cadmium Box Plots by Sampling Port



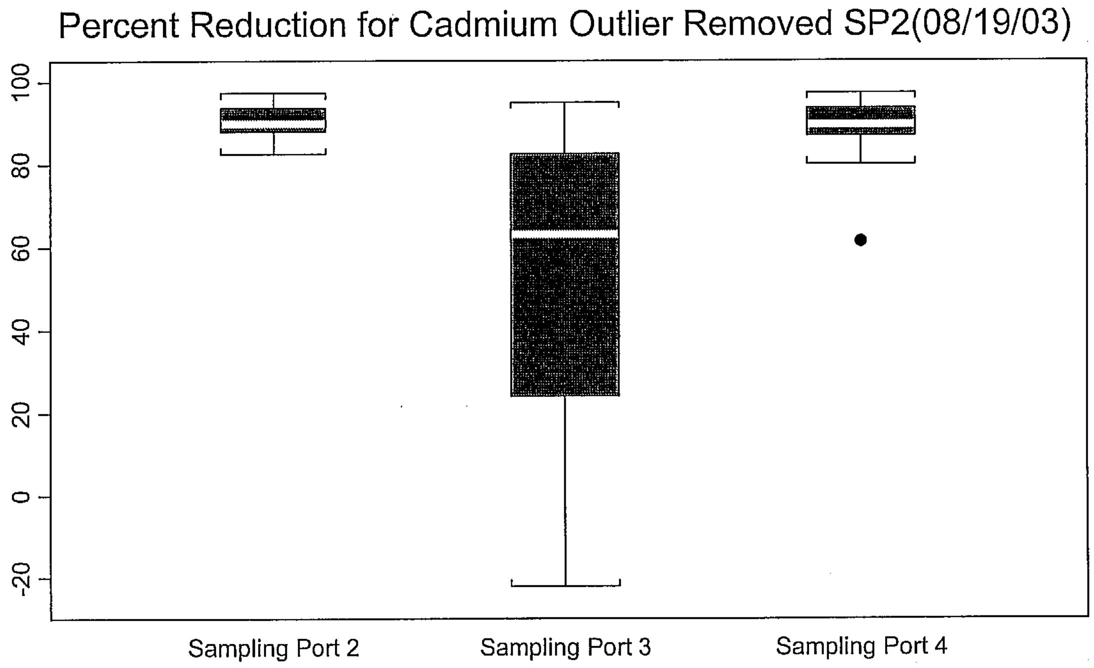
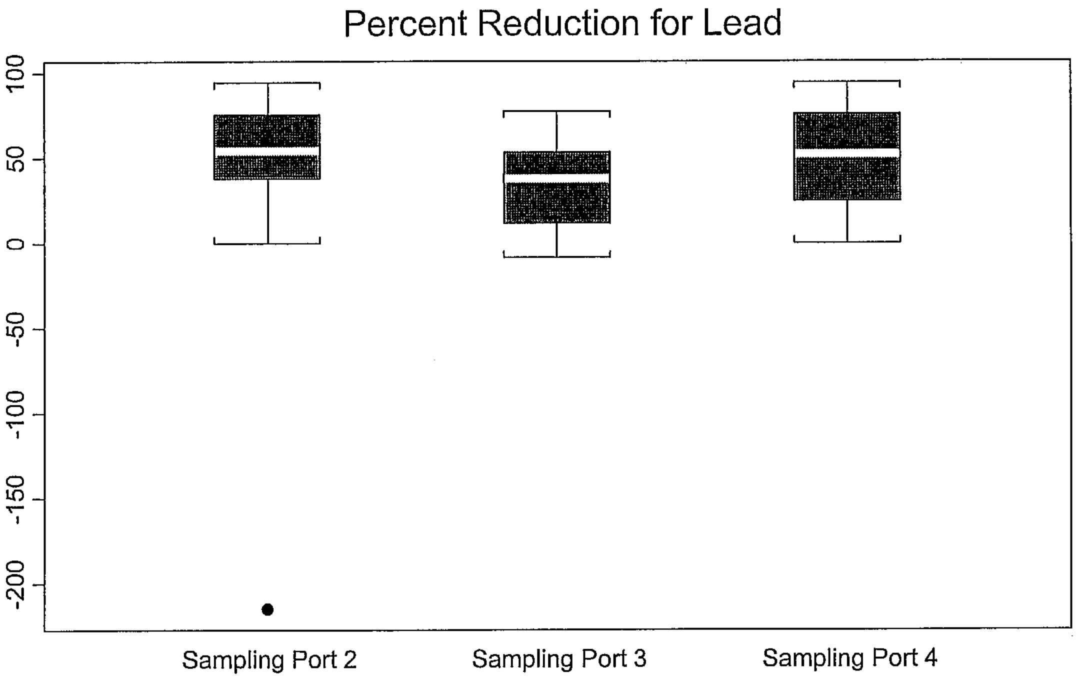


Figure 2. Lead Box Plots by Sampling Port



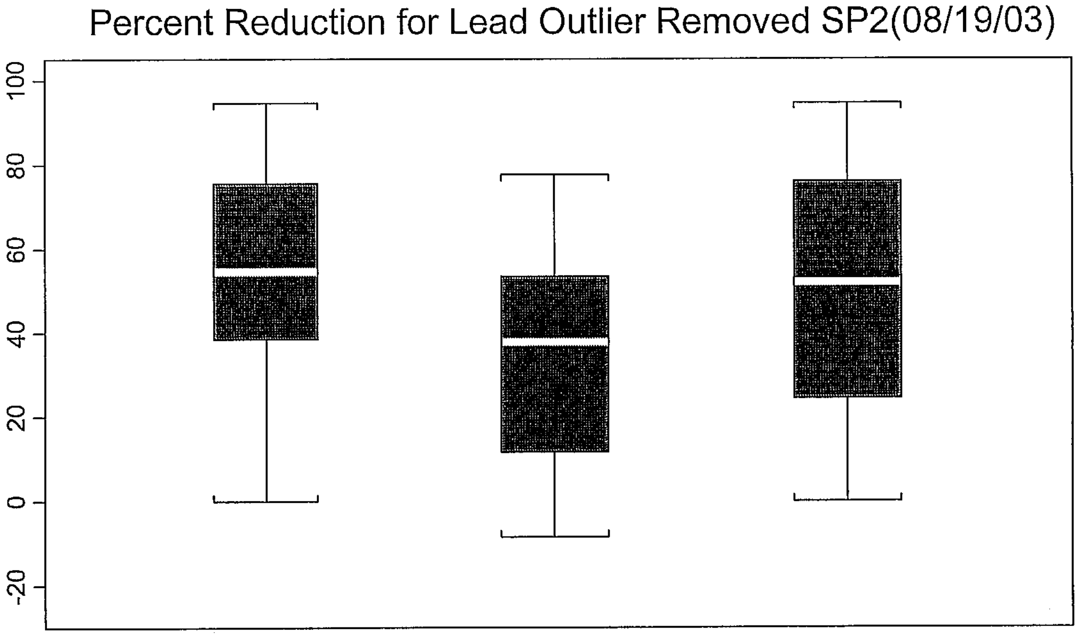
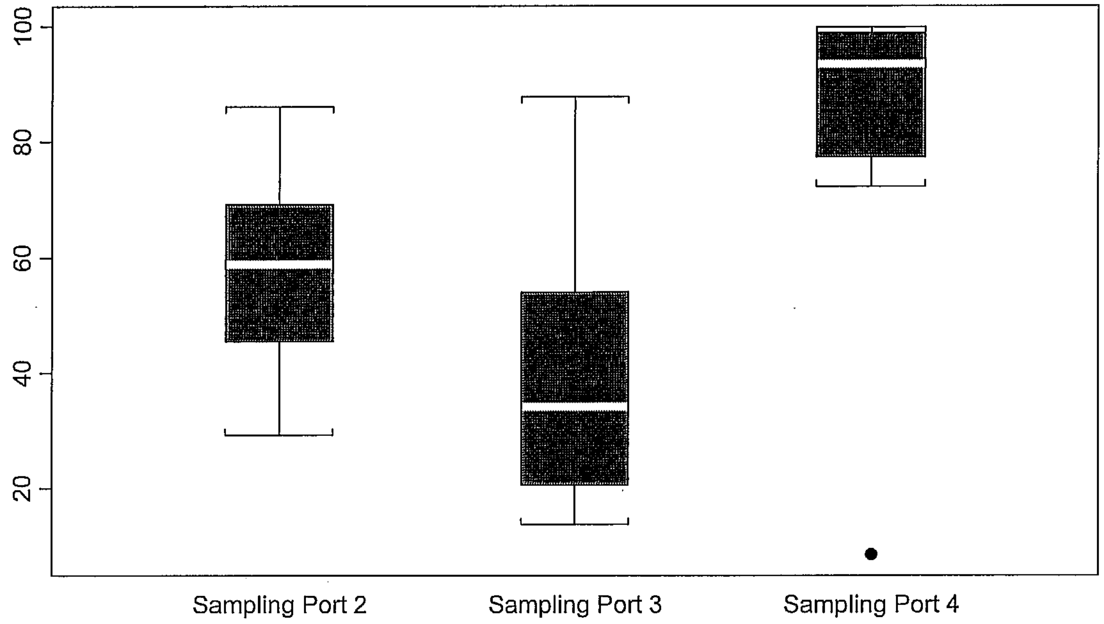


Figure 3. Zinc Box Plots by Sampling Port

Percent Reduction for Zinc



Percent Reduction for Zinc Outlier Removed SP4(02/26/03)

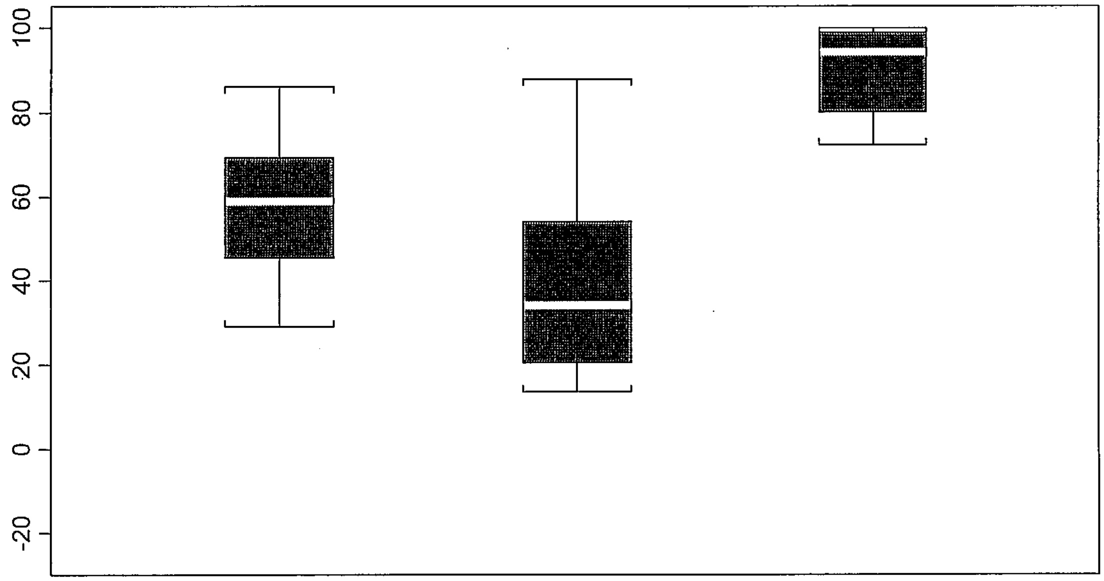
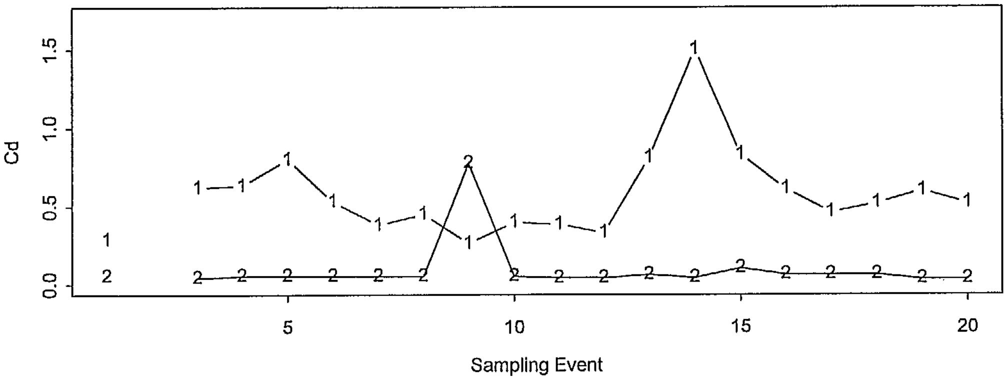
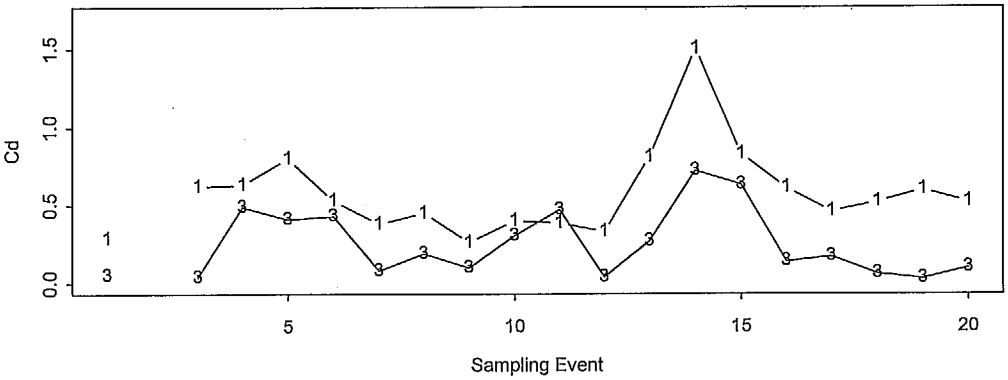


Figure 4. Cadmium Time Plots by Sampling Port

Sampling Ports 1 and 2



Sampling Ports 1 and 3



Sampling Ports 1 and 4

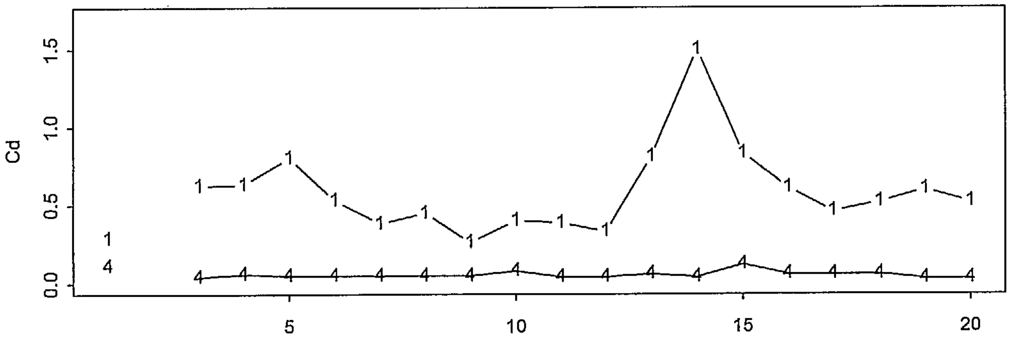
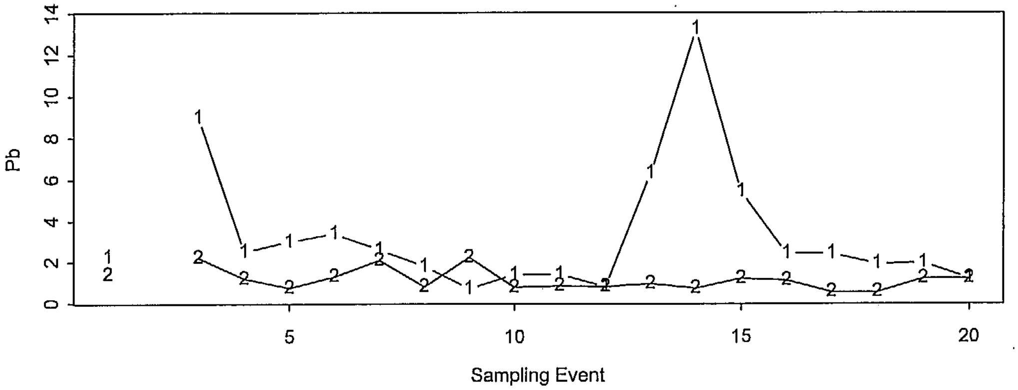
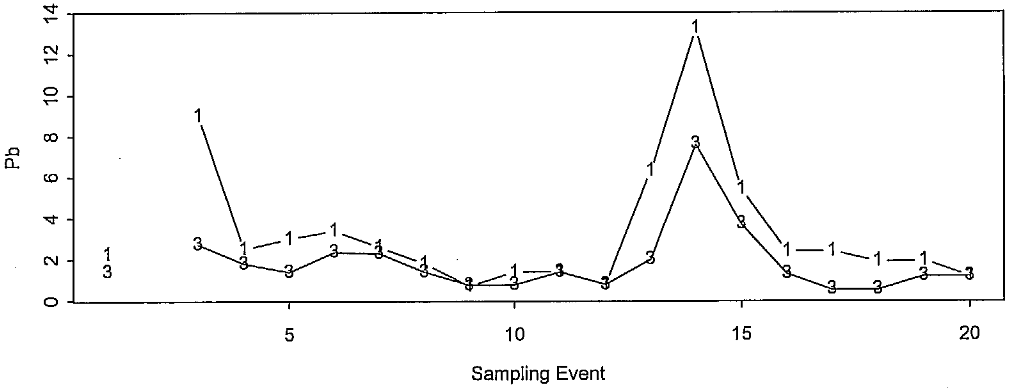


Figure 5. Lead Time Plots by Sampling Port

Sampling Ports 1 and 2



Sampling Ports 1 and 3



Sampling Ports 1 and 4

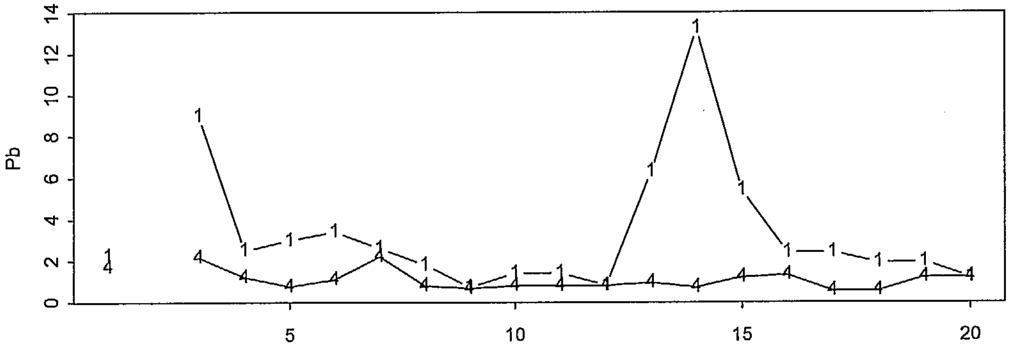
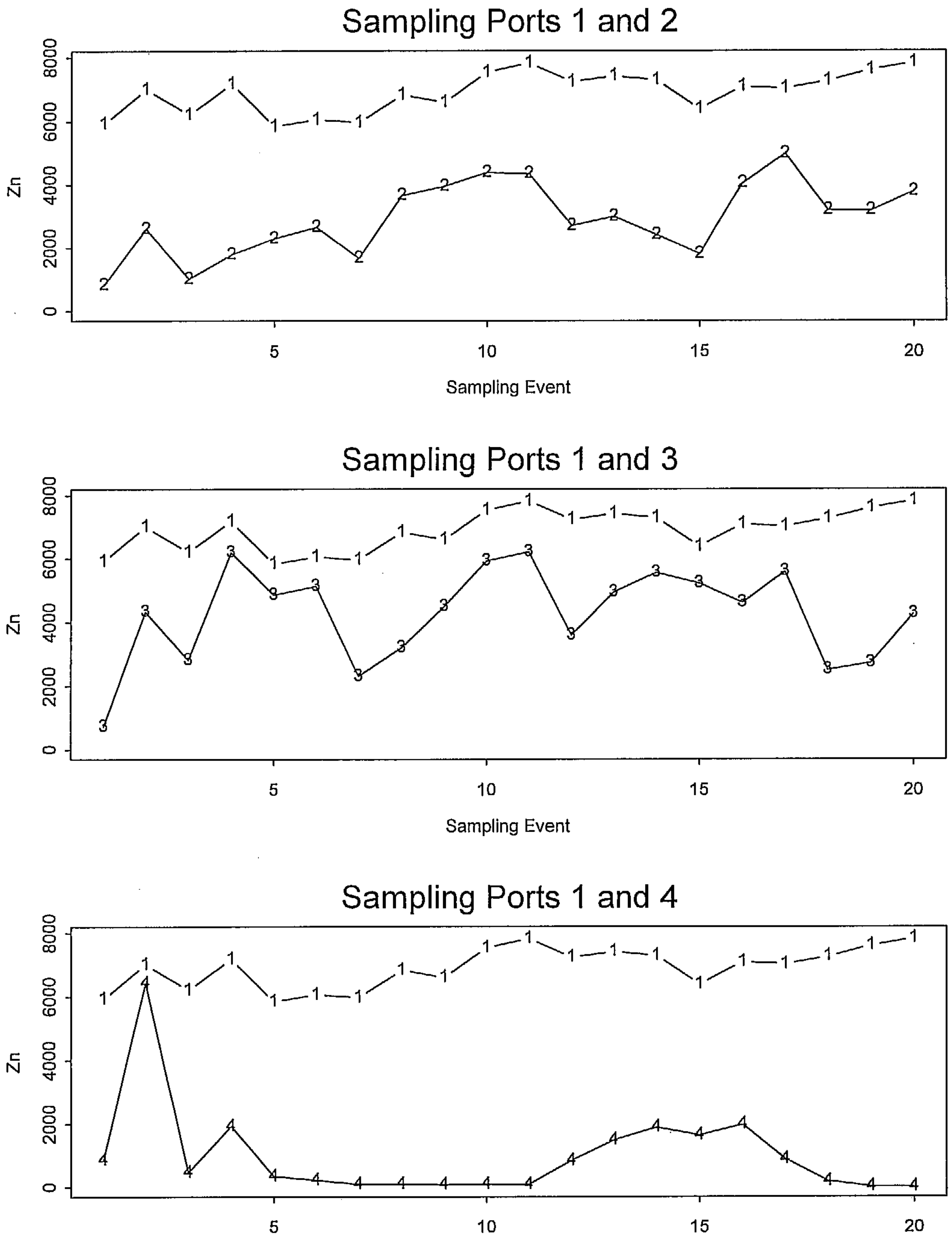


Figure 6. Zinc Time Plots by Sampling Port



Appendix A

A *boxplot* is a rectangle, the top and bottom of the rectangle represent the upper and lower quartiles of the data, the horizontal line within the rectangle represents the median. Lines, in the shape of a "T", extend from the box to the nearest value not beyond a *standard span* from the quartiles. These lines are often referred to as whiskers. Values beyond the end of the whiskers are drawn individually. The *standard span* is 1.5·Inter-Quartile Range (IQR).

The *quantile* of the data is a number that divides the data into two groups, so that a fraction of observations fall below the quantile and a fraction fall above the quantile. For example, the 75th quantile (Q(.75)) divides the data set such that three fourths of the observations fall below Q(.75) and one fourth fall above.

The width of the box plot is proportional to the square root of the number of observations for the box.

Note: The *median* is the 50th quantile, Q(.50).
The *upper quartile* is the 75th quantile, Q(.75).
The *lower quartile* is the 25th quantile, Q(.25).
The *IQR* = Q(.75) − Q(.25).

The *Kruskal-Wallis test* is a non-parametric test for location differences (a non-parametric test does not require any distributional assumptions like normality). The test statistic is constructed using the ranks of the data.