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Active and Semi-Passive Lime Treatment of Acid Mine Drainage at Leviathan Mine, California

Innovative Technology Evaluation Report

National Risk Management Research Laboratory
Office of Research and Development
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Notice

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Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

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Sally C. Gutierrez, Director
National Risk Management Research Laboratory

Abstract

As part of the Superfund Innovative Technology Evaluation (SITE) program, U.S. Environmental Protection Agency (EPA) National Risk Management Research Laboratory (NRMRL), in cooperation with EPA Region IX, the state of California, and the Atlantic Richfield Company (ARCO) evaluated lime treatment of acid mine drainage (AMD) and acid rock drainage (ARD) at the Leviathan Mine Superfund site located in Alpine County, California. EPA evaluated two lime treatment systems in operation at the mine in 2002 and 2003: an active lime treatment system operated in biphasic and monophasic modes, and a semi-passive alkaline lagoon treatment system. The treatment systems utilize the same chemistry to treat AMD generated within the mine workings and ARD generated from surface seeps within waste rock; the addition of lime to neutralize acidity and remove toxic levels of metals by precipitation. The primary metals of concern in the AMD and ARD include aluminum, arsenic, copper, iron, and nickel; secondary water quality indicator metals include cadmium, chromium, lead, selenium, and zinc.

The technology evaluation occurred between June 2002 and October 2003, during the operation of both the active lime treatment system (in biphasic and monophasic modes) and the semi-passive alkaline lagoon treatment system. The evaluation consisted of multiple sampling events of each treatment system during 6 months of operation separated by winter shutdown. Throughout the evaluations, EPA collected metals data on each system's influent and effluent streams, documented metals removal and reduction in acidity within each system's unit operations, and recorded operational information pertinent to the evaluation of each treatment system. EPA evaluated the treatment systems independently, based on removal efficiencies for primary and secondary target metals, comparison of effluent concentrations to discharge standards mandated by EPA in 2002, and on the characteristics of resulting metals-laden solid wastes. Removal efficiencies of individual unit operations were also evaluated.

Both treatment systems were shown to be extremely effective at neutralizing acidity and reducing the concentrations of the 10 target metals in the AMD and ARD flows at Leviathan Mine to below EPA discharge standards. Although the influent concentrations for the primary target metals were up to 3,000 fold above the EPA discharge standards, both lime treatment systems were successful in reducing the concentrations of the primary target metals in the AMD and ARD to between 4 and 20 fold below EPA discharge standards. In general, removal efficiencies for the five primary target metals exceeded 95 percent. In addition, the active lime treatment system operated in biphasic mode was shown to be very effective at separating arsenic from the AMD prior to precipitation of other metals, subsequently reducing the total volume of hazardous solid waste produced by the treatment system. Separating the arsenic into a smaller solid waste stream significantly reduces materials handling and disposal costs.

Based on the success of lime treatment at the Leviathan Mine site, the state of California will continue to treat AMD at the site using the active lime treatment system in biphasic mode and ARCO will continue to treat ARD using the semi-passive alkaline lagoon treatment system.

Contents

Notice ii
Foreword iii
Abstract iv
Acronyms, Abbreviations, and Symbols ix
Conversion Factors xi
Acknowledgements xii

Section 1 Introduction 1
1.1 Project Background 1
1.2 The Site Demonstration Program and Reports 1
1.3 Purpose of the Innovative Technology Evaluation Report 3
1.4 Technology Description 3
1.5 Key Findings 4
1.6 Key Contacts 8

Section 2 Technology Effectiveness 11
2.1 Background 11
2.1.1 Site Description 11
2.1.2 History of Contaminant Release 13
2.1.3 Previous Actions 13
2.2 Process Description 13
2.2.1 Active Lime Treatment System 14
2.2.2 Semi-Passive Alkaline Lagoon Treatment System 15
2.3 Evaluation Approach 15
2.3.1 Project Objectives 15
2.3.2 Sampling Program 16
2.4 Field Evaluation Activities 17
2.4.1 Mobilization Activities 17
2.4.2 Operation and Maintenance Activities 17
2.4.2.1 Active Lime Treatment System 17
2.4.2.2 Semi-Passive Alkaline Lagoon Treatment System 18
2.4.3 Process Modifications 18
2.4.3.1 Active Lime Treatment System 18
2.4.3.2 Semi-Passive Alkaline Lagoon Treatment System 19
2.4.4 Evaluation Monitoring Activities 19
2.4.4.1 Active Lime Treatment System 19
2.4.4.2 Semi-Passive Alkaline Lagoon Treatment System 19
2.4.5 Demobilization Activities 20
2.4.6 Lessons Learned 20
2.5 Technology Evaluation Results 21
2.5.1 Primary Objective No.1: Evaluation of Metals Removal Efficiencies 21
2.5.2 Primary Objective No.2: Comparison of Effluent Data to Discharge Standards .. 23

Contents (continued)

2.5.3 Secondary Objectives for Evaluation of Active Lime Treatment System Unit Operations 25
2.5.3.1 Operating Conditions 26
2.5.3.2 Reaction Chemistry 27
2.5.3.3 Metals Removal By Unit Operation 29
2.5.3.4 Solids Separation 31
2.5.4 Secondary Objectives for Evaluation of Semi-Passive Alkaline Lagoon Treatment System Unit Operations 32
2.5.4.1 Operating Conditions 32
2.5.4.2 Reaction Chemistry 33
2.5.4.3 Metals Removal By Unit Operation 34
2.5.4.4 Solids Separation 35
2.5.5 Evaluation of Solids Handling and Disposal 36
2.5.5.1 Waste Characterization and Handling Requirements 36
2.5.5.2 Active Lime Treatment System 36
2.5.5.3 Semi-Passive Alkaline Lagoon Treatment System 38

Section 3 Technology Applications Analysis 39
3.1 Key Features 39
3.2 Applicable Wastes 39
3.3 Factors Affecting Performance 40
3.4 Technology Limitations 40
3.5 Range of Suitable Site Characteristics 41
3.6 Personnel Requirements 41
3.7 Materials Handling Requirements 42
3.8 Permit Requirements 42
3.9 Community Acceptance 42
3.10 Availability, Adaptability, and Transportability of Equipment 43
3.11 Ability to Attain ARARs 43
3.11.1 Comprehensive Environmental Response, Compensation, and Liability Act 44
3.11.2 Resource Conservation and Recovery Act 44
3.11.3 Clean Air Act 46
3.11.4 Clean Water Act 46
3.11.5 Safe Drinking Water Act 46
3.11.6 Occupational Safety and Health Act 46
3.11.7 State Requirements 47
3.12 Technology Applicability To Other Sites 47

Section 4 Economic Analysis 49
4.1 Introduction 49
4.2 Cost Summary 49
4.3 Factors Affecting Cost Elements 50
4.4 Issues and Assumptions 50
4.5 Cost Elements 51
4.5.1 Site Preparation 51
4.5.2 Permitting and Regulatory Requirements 51
4.5.3 Capital Equipment 51
4.5.4 Startup and Fixed Costs 53
4.5.5 Consumables and Supplies 53
4.5.6 Labor 53
4.5.7 Utilities 54
4.5.8 Residual Waste Shipping, Handling, and Disposal 54
4.5.9 Analytical Services 54

Contents (continued)

4.5.10 Maintenance and Modifications 54
4.5.11 Demobilization 55

Section 5 Data Quality Review 56
5.1 Deviations From TEP/QAPP 56
5.2 Summary of Data Evaluation and PARCC Criteria Evaluation 57

Section 6 Technology Status 59
References 60

Appendix A Sample Collection And Analysis Tables 61
Appendix B Data Used To Evaluate Project Primary Objectives 71
Appendix C Detailed Cost Element Spreadsheets 83

Tables

Table Page

1-1 Active Lime Treatment System Removal Efficiencies: Biphasic Operation in 2002 and 2003 9
1-2 Active Lime Treatment System Removal Efficiencies: Monophasic Operation in 2003 9
1-3 Semi-Passive Alkaline Lagoon Treatment System Removal Efficiencies in 2002 9
1-4 Determination of Hazardous Waste Characteristics for Solid Waste Streams at Leviathan Mine 10

2-1 Summary of Historical Metals of Concern 14
2-2 2002 and 2003 Removal Efficiencies for the Active Lime Treatment System - Biphasic Operation 22
2-3 2003 Removal Efficiencies for the Active Lime Treatment System - Monophasic Operation 22
2-4 2002 Removal Efficiencies for the Semi-Passive Alkaline Lagoon Treatment System 23
2-5 EPA Project Discharge Standards 23
2-6 Results of the Student's-t Test Statistical Analysis for Maximum Daily Effluent Data 24
2-7 Results of the Student's-t Test Statistical Analysis for 4-Day Average Effluent Data 25
2-8 Biphasic Unit Operation Parameters 26
2-9 Monophasic Unit Operation Parameters 27
2-10 Biphasic Phase I Unit Operation Reaction Chemistry 28
2-11 Biphasic Phase II Unit Operation Reaction Chemistry 29
2-12 Monophasic Unit Operation Reaction Chemistry 30
2-13 Biphasic Unit Operation Metals Removal Efficiencies 30
2-14 Monophasic Unit Operation Removal Efficiencies 31
2-15 Biphasic Phase I and Phase II Solids Separation Efficiencies 32
2-16 Monophasic Solids Separation Efficiencies 33
2-17 Alkaline Lagoon Unit Operation Parameters 33
2-18 Alkaline Lagoon Unit Operation Reaction Chemistry 34
2-19 Alkaline Lagoon Unit Operation Metals Removal Efficiencies 35
2-20 Alkaline Lagoon Solids Separation Efficiencies 35
2-21 Active Lime Treatment System Waste Characterization 37
2-22 Semi-Passive Alkaline Lagoon Treatment System Waste Characterization 38

3-1 Determination of Hazardous Waste Characteristics for Solid Waste Streams at Leviathan Mine 43
3-2 Federal Applicable or Relevant and Appropriate Requirements for Both Lime Treatment Systems 45
3-3 Feasibility Study Criteria Evaluation for Both Lime Treatment Systems at Leviathan Mine 48

4-1 Summary of Total and Variable Costs for Each Treatment System 50
4-2 Summary of Cost Elements for the Active Lime Treatment System 52
4-3 Summary of Cost Elements for the Semi-passive Alkaline Lagoon Treatment System 52

Figures

Figure Page

1-1 Site Location Map 2
1-2 Active Lime Treatment System Monophasic Schematic 5
1-3 Active Lime Treatment System Biphasic Schematic 6
1-4 Semi-passive Lagoon Treatment System Schematic 7

2-1 Site Layout 12

Acronyms, Abbreviations, and Symbols

μg/L	Microgram per liter
μmhos/cm	Micromhos per centimeter
°C	Degree Celsius
ACQR	Air quality control region
AMD	Acid mine drainage
AQMD	Air quality management district
ARAR	Applicable or relevant and appropriate requirements
ARCO	Atlantic Richfield Company
ARD	Acid rock drainage
CAA	Clean Air Act
CERCLA	Comprehensive Emergency Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CRDL	Contract required detection limit
CUD	Channel under drain
CWA	Clean Water Act
DI	Deionized water
DO	Dissolved oxygen
DOT	Department of Transportation
EE/CA	Engineering evaluation cost analysis
EPA	U.S. Environmental Protection Agency
g/L	Gram per liter
HDPE	High density polyethylene
HRT	Hydraulic residence time
ICP	Inductively coupled plasma
ITER	Innovative Technology Evaluation Report
kg	Kilogram
kg/day	Kilogram per day
kW	Kilowatt
L/min	Liter per minute
MCL	Maximum contaminant level
MCLG	Maximum contaminant level goal

Acronyms, Abbreviations, and Symbols (continued)

MD	Matrix duplicate
mg/kg	Milligram per kilogram
mg/L	Milligrams per liter
mL	Milliliter
mL/min	Milliliter per minute
MS	Matrix spike
mV	Millivolt
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NPDES	National Pollutant Discharge and Elimination System
NRMRL	National Risk Management Research Laboratory
ORP	Oxidation reduction potential
OSHA	Occupational Safety and Health Administration
PARCC	Precision, accuracy, representativeness, completeness, and comparability
pH	Negative logarithm of the hydrogen ion concentration
POTW	Publicly-owned treatment works
PPE	Personal protection equipment
PQL	Practical quantitation limit
PUD	Pit under drain
QA/QC	Quality assurance/quality control
RCRA	Resource Conservation and Recovery Act
RPD	Relative percent difference
rpm	Revolution per minute
RWQCB	California Regional Water Quality Control Board – Lahontan Region
SARA	Superfund Amendment and Reauthorization Act
SCADA	Supervisory Control and Data Acquisition
SDG	Sample delivery group
SDWA	Safe Drinking Water Act
SITE	Superfund Innovative Technology Evaluation
SPLP	Synthetic precipitation and leaching procedure
STLC	Soluble threshold limit concentration
TCLP	Toxicity characteristic leaching procedure
TDS	Total dissolved solids
TEP/QAPP	Technology Evaluation Plan/Quality Assurance Project Plan
Tetra Tech	Tetra Tech EM Inc.
TOM	Task order manager
TSD	Treatment, storage, and disposal
TSS	Total suspended solids
TTLC	Total threshold limit concentration
USACE	US Army Corp of Engineers
WET	Waste extraction test

Conversion Factors

	To Convert From	*To*	*Multiply By*
Length:	Centimeter	Inch	0.3937
	Meter	Foot	3.281
	Kilometer	Mile	0.6214
Area:	Square Meter	Square Foot	10.76
Volume:	Liter	Gallon	0.2642
	Cubic Meter	Cubic Foot	35.31
	Cubic Meter	Cubic Yard	1.308
Mass:	Kilogram	Pound	2.2046
	Metric Ton	Short Ton	1.1025
Energy:	Kilowatt-hour	British Thermal Unit	3413
Power:	Kilowatt	Horsepower	1.34
Temperature:	°Celsius	(°Fahrenheit + 32)	1.8

Acknowledgements

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This project consisted of the demonstration of two innovative technologies under the SITE program to evaluate the semi-passive alkaline lagoon treatment system developed by Atlantic Richfield Company (ARCO) and the active lime treatment system developed by Unipure Environmental. The technology demonstrations were conducted on acid mine and acid rock drainage at the Leviathan Mine Superfund site in Alpine County, California. Both technologies are currently being used as interim actions at the site, pending completion of a remedial investigation, feasibility study, and record of decision. This Innovative Technology Evaluation Report (ITER) interprets the data that were collected during the two-year demonstration period and discusses the potential applicability of each technology to other mine sites.

The cooperation and participation of the following people are gratefully acknowledged: Mr. Scott Jacobs of NRMRL, Mr. Chris Stetler and Mr. Doug Carey of the California Regional Water Quality Control Board-Lahontan Region, Mr. Dan Ferriter of ARCO, Mr. Andy Slavik of Unipure Environmental, and Ms. Monika Johnson of EMC^2.

SECTION 1
INTRODUCTION

This section provides background information about the Superfund Innovative Technology Evaluation (SITE) Program and the SITE demonstration that was conducted at an abandoned mine site in Alpine County, California, discusses the purpose of this Innovative Technology Evaluation Report (ITER), and briefly describes the technology that was evaluated. Key contacts are listed at the end of this section for inquiries regarding additional information about the SITE Program, the evaluated technology, and the demonstration site.

1.1 Project Background

The U.S. Environmental Protection Agency (EPA), the states, and the Federal Land Management Agencies all need better tools to manage acid mine drainage (AMD) and acid rock drainage (ARD) at abandoned mine sites. Over a 12-month period during 2002 and 2003, EPA evaluated the use of lime for removal of high concentrations of metals from AMD and ARD generated at an abandoned mine site, Leviathan Mine, located northwest of Monitor Pass in northeastern Alpine County, California (see Figure 1-1). The lime treatment SITE demonstration was conducted by EPA under the SITE Program, which is administered by EPA's National Risk Management Research Laboratory (NRMRL), Office of Research and Development. The SITE demonstration was conducted by EPA in cooperation with EPA Region IX, the state of California, and Atlantic Richfield Company (ARCO).

The lime treatment systems in operation at Leviathan Mine include an active lime treatment system installed by the state of California in 1999, and a semi-passive lagoon treatment system installed by ARCO in 2001. The lime treatment systems were specifically designed to treat high flow rates of AMD and ARD containing thousands of milligrams per liter (mg/L) of metals at a pH as low as 2.0. Without treatment, the AMD and ARD from the mine would otherwise be released to the environment. The SITE demonstration consisted of multiple sampling events of each treatment system during 6 months of operation separated by winter shutdown. Throughout the SITE demonstration, EPA collected metals data on each system's influent and effluent streams, documented metals removal and reduction in acidity within each system's unit operations, and recorded operational information pertinent to the evaluation of each treatment system. EPA evaluated the treatment systems independently, based on removal efficiencies for primary and secondary target metals, comparison of effluent concentrations to discharge standards mandated by EPA in 2002, and on the characteristics of resulting metals-laden solid wastes. Removal efficiencies of individual unit operations were also evaluated. A summary of the SITE demonstration and the results of the lime treatment technology evaluation are presented in Sections 2 through 5 of this report.

1.2 The SITE Demonstration Program and Reports

In 1980, the U.S. Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund. CERCLA is committed to protecting human health and the environment from uncontrolled hazardous waste sites. In 1986, CERCLA was amended by the Superfund Amendments and Reauthorization Act (SARA). These amendments emphasize the achievement of long-term effectiveness and permanence of remedies at Superfund sites. SARA mandates the use of permanent solutions, alternative treatment technologies, or resource recovery technologies, to the maximum extent possible, to clean up hazardous waste sites.

State and Federal agencies, as well as private parties, have for several years now been exploring the growing number of innovative technologies for treating hazardous wastes. EPA has focused on policy, technical, and informational issues related to the exploring and applying new remediation technologies applicable to Superfund sites. One such initiative is EPA's SITE Program, which was established to accelerate the development, demonstration, and use of innovative technologies for site cleanups. The SITE

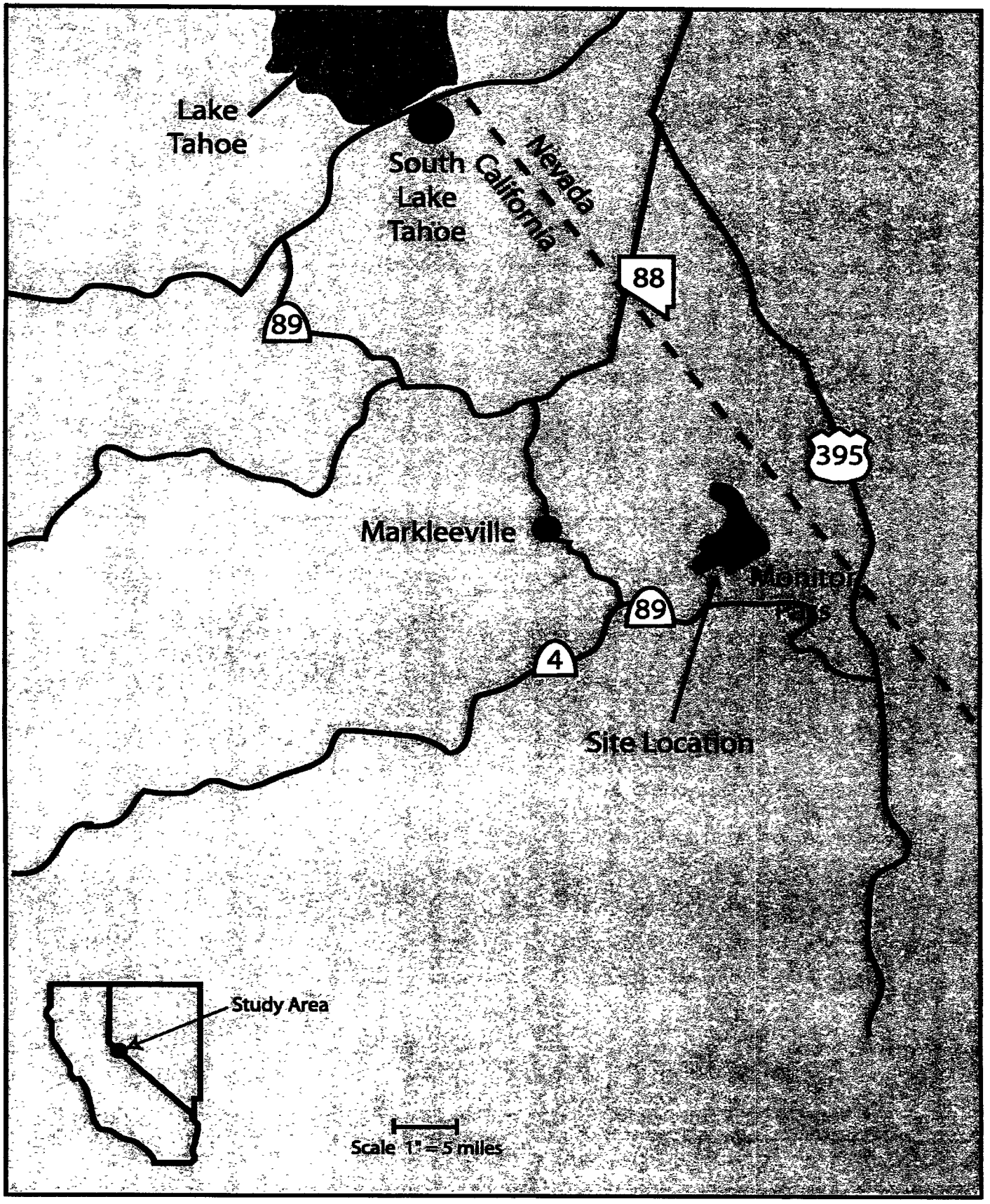

Figure 1-1. Site Location Map

Program's primary purpose is to maximize the use of alternatives in cleaning hazardous waste sites by encouraging the development and demonstration of new, innovative treatment and monitoring technologies. It consists of three major elements: the Demonstration Program, the Consortium for Site Characterization Technologies, and the Technology Transfer Program.

The objective of the Demonstration Program is to develop reliable performance and cost data on innovative technologies so that potential users can assess the technology's site-specific applicability. Technologies evaluated are either available commercially or are close to being available for full-scale remediation of Superfund sites. SITE demonstrations usually are conducted at hazardous waste sites under conditions that closely simulate full-scale remediation conditions, thus assuring the usefulness and reliability of the information collected. Data collected are used to assess: (1) the performance of the technology; (2) the potential need for pre- and post treatment of wastes; (3) potential operating problems; and (4) the approximate costs. The demonstration also provides opportunities to evaluate the long term risks and limitations of a technology.

At the conclusion of a SITE demonstration, EPA prepares a Demonstration Bulletin, Technology Capsule, and an ITER. These reports evaluate all available information on the technology and analyze its overall applicability to other potential sites characteristics, waste types, and waste matrices. Testing procedures, performance and cost data, and quality assurance and quality standards are also presented. The Technology Bulletin consists of a one to two page summary of the SITE demonstration and is prepared as a mailer for public notice. The Technology Bulletin provides a general overview of the technology demonstrated, results of the demonstration, and telephone numbers and e-mail address for the EPA project manager in charge of the SITE evaluation. In addition, references to other related documents and reports are provided. The Technology Capsule consists of a more in-depth summary of the SITE demonstration and is usually about 10 pages in length. The Technology Capsule presents information and summary data on various aspects of the technology including applicability, site requirements, performance, process residuals, limitations, and current status of the technology. The Technology Capsule is designed to help EPA remedial project managers and on-scene coordinators, contractors, and other site cleanup managers understand the types of data and site characteristics needed to effectively evaluate the technology's applicability for cleaning Superfund sites. The final SITE document produced is the ITER. The ITER consists of an in-depth evaluation of the SITE demonstration including details on field activities and operations, performance data and statistical evaluations, economic analysis, applicability, and effectiveness, as discussed in the following section.

1.3 Purpose of the Innovative Technology Evaluation Report

The ITER is designed to aid decision-makers in evaluating specific technologies for further consideration as applicable options in a particular cleanup operation. The ITER should include a comprehensive description of the SITE demonstration and its results, and is intended for use by EPA remedial project managers, EPA on-scene coordinators, contractors, and other decision-makers carrying out specific remedial actions.

To encourage the general use of demonstrated technologies, EPA provides information regarding the applicability of each technology to specific sites and wastes. The ITER includes information on cost and desirable site-specific characteristics. It also discusses advantages, disadvantages, and limitations of the technology. However, each SITE demonstration evaluates the performance of a technology in treating a specific waste matrix at a specific site. The characteristics of other wastes and other sites may differ from the characteristics at the demonstration site. Therefore, a successful field demonstration of a technology at one site does not necessarily ensure that it will be applicable at other sites. Data from the field demonstration may require extrapolation for estimating the operating ranges in which the technology will perform satisfactorily. Only limited conclusions can be drawn from a single field demonstration.

This ITER provides information on new approaches to the use of lime addition to reduce the concentration of toxic metals and acidity in AMD and ARD at Leviathan Mine, and is a critical step in the development and commercialization of lime treatment for use at other applicable mine sites.

1.4 Technology Description

Lime treatment of AMD and ARD is a relatively simple chemical process where low pH AMD/ARD is neutralized using lime to precipitate dissolved iron, the main component of AMD and ARD, and other dissolved metals as metal hydroxides and oxy-hydroxides. In the active lime treatment system, the precipitation process is either performed in a single stage (monophasic mode), or two stages (biphasic mode). In the monophasic mode, the pH of the acid mine flow is raised to precipitate out all of the target metals resulting in a large quantity of metals-laden sludge. The precipitation occurs under the following reaction:

$$Ca(OH)_{2\,(s)} + Me^{2+}/Me^{3+}{}_{(aq)} + H_2SO_4 \rightarrow Me(OH)_2/Me(OH)_{3(s)} + CaSO_{4\,(s)} + H_2O \qquad (1)$$

Where Me^{2+}/Me^{3+} = dissolved metal ion in either a +2 or +3 valence state

The optimum pH range for this precipitation reaction is between 7.9 and 8.2. Along with metal hydroxides, excess sulfate in the AMD and ARD precipitates with excess calcium as calcium sulfate (gypsum). However, because sulfate removal is not a goal of the process, the treatment system is optimized for metals removal, leaving excess sulfate in solution. The active lime treatment system consists of reaction tanks, flash/floc mixing tanks, plate clarifiers, and a filter press. The active lime treatment system operated in monophasic mode was used at Leviathan Mine to treat a mixture of AMD and ARD with varying concentrations of arsenic. The monophasic configuration of the active lime treatment system is shown in Figure 1-2.

The active lime treatment system operated in biphasic mode is preferred at Leviathan Mine for treating AMD where concentrations of arsenic are high enough to yield a solid waste stream requiring handling as a hazardous waste. In this case, the active lime treatment system generates a small quantity of precipitate during the first reaction (Phase I) that contains high arsenic concentrations. A large quantity of low-arsenic content precipitate is generated during the second reaction (Phase II). Separating the arsenic into a smaller solid waste stream significantly reduces the cost of disposal.

During Phase I, lime is added to raise the pH high enough to generate a ferric iron hydroxide precipitate, while leaving the majority of other metals in solution.

$$3Ca(OH)_{2\,(s)} + 2Fe^{3+}{}_{(aq)} \rightarrow 3Ca^{2+}{}_{(aq)} + 2Fe(OH)_{3\,(s)} \quad (2)$$

The optimum pH range for this precipitation reaction is between 2.8 and 3.0. During precipitation, a large portion of the arsenic adsorbs to the ferric hydroxide precipitate. The solution pH remains nearly constant in this zone as long as excess soluble iron is available to buffer the addition of lime. Given enough reaction time, it is in this zone (pH 2.8 to 3.0) that maximum arsenic removal occurs. The small quantity of iron and arsenic rich precipitate generated is dewatered using a filter press. After dewatering, the small amount of Phase I filter cake generated typically exhibits hazardous characteristics due to the high concentration of arsenic and is shipped off site for disposal at a treatment, storage, and disposal (TSD) facility.

In Phase II of the biphasic process, the pH is further raised through lime addition to precipitate out the remaining target metals forming a large quantity of Phase II sludge, as described in Reaction (1) above. Again, the optimum pH range for the second precipitation reaction is between 7.9 and 8.2. The Phase II sludge typically does not exhibit hazardous waste characteristics because the majority of the arsenic was removed in Phase I. The Phase II pit clarifier sludge is typically disposed of on site. The biphasic configuration of the active lime treatment system utilizes the same equipment as the monophasic configuration, though operated in a two-step process, and includes the addition of an extended settling pit clarifier, as shown in Figure 1-3.

The semi-passive alkaline lagoon treatment system is a continuous flow lime contact system, also designed for metal hydroxide precipitation. This system was designed to treat the ARD at Leviathan Mine, which has low arsenic content. The system consists of air sparge/lime contact tanks where initial precipitation occurs, and bag filters that capture approximately 60 percent of the precipitate. The system relies on iron oxidation during mechanical aeration, optimization of lime dosage, and adequate cake thickness within each bag filter to filter precipitate from the treated ARD. The system also includes a multi-cell settling lagoon for extended lime contact and final precipitation of metal hydroxides. Bag filter solids are typically disposed of on site. The reaction chemistry is the same as the active lime treatment system operated in monophasic mode, as described in Reaction (1). A process flow diagram for the alkaline lagoon lime treatment system is presented in Figure 1-4.

1.5 Key Findings

Both lime treatment systems were shown to be extremely effective at neutralizing acidity and reducing the concentrations of the 10 target metals in the AMD and ARD flows at Leviathan Mine to below EPA discharge standards. The active lime treatment system treated 28.3 million liters of AMD operating in the biphasic mode using 125 dry tons of lime; and 17.4 million liters of combined AMD and ARD operating in monophasic mode using 23.8 dry tons of lime. The semi-passive alkaline lagoon treatment system treated 12.3 million liters of ARD using 19.4 dry tons of lime. The active lime treatment system operated in Biphasic mode was shown to be very effective at separating arsenic from the AMD prior to precipitation of other metals, subsequently reducing the total volume of hazardous solid waste produced by the treatment system. Separating the arsenic into a smaller solid waste stream significantly reduces materials handling and disposal costs.

Although the influent concentrations for the primary target metals were up to 3,000 fold above the EPA discharge standards, both lime treatment systems were successful in reducing the concentrations of the primary target metals in the AMD and ARD to between 4 and 20 fold below the discharge standards. For both modes of the active lime treatment system, the average removal efficiency for the primary target metals was 99.6 percent over 20 sampling events, with the exception of lead at 74.6 to 78.3 percent removal. For the semi-passive alkaline lagoon treatment system, the average removal efficiency for the primary target metals in the ARD was 99.2 percent over eight sampling events, with the exception of lead at 66.4 percent removal and copper at 58.3 percent removal. Removal efficiencies for lead and copper were less than other metals because the influent concentrations of these two metals were already near or below the EPA

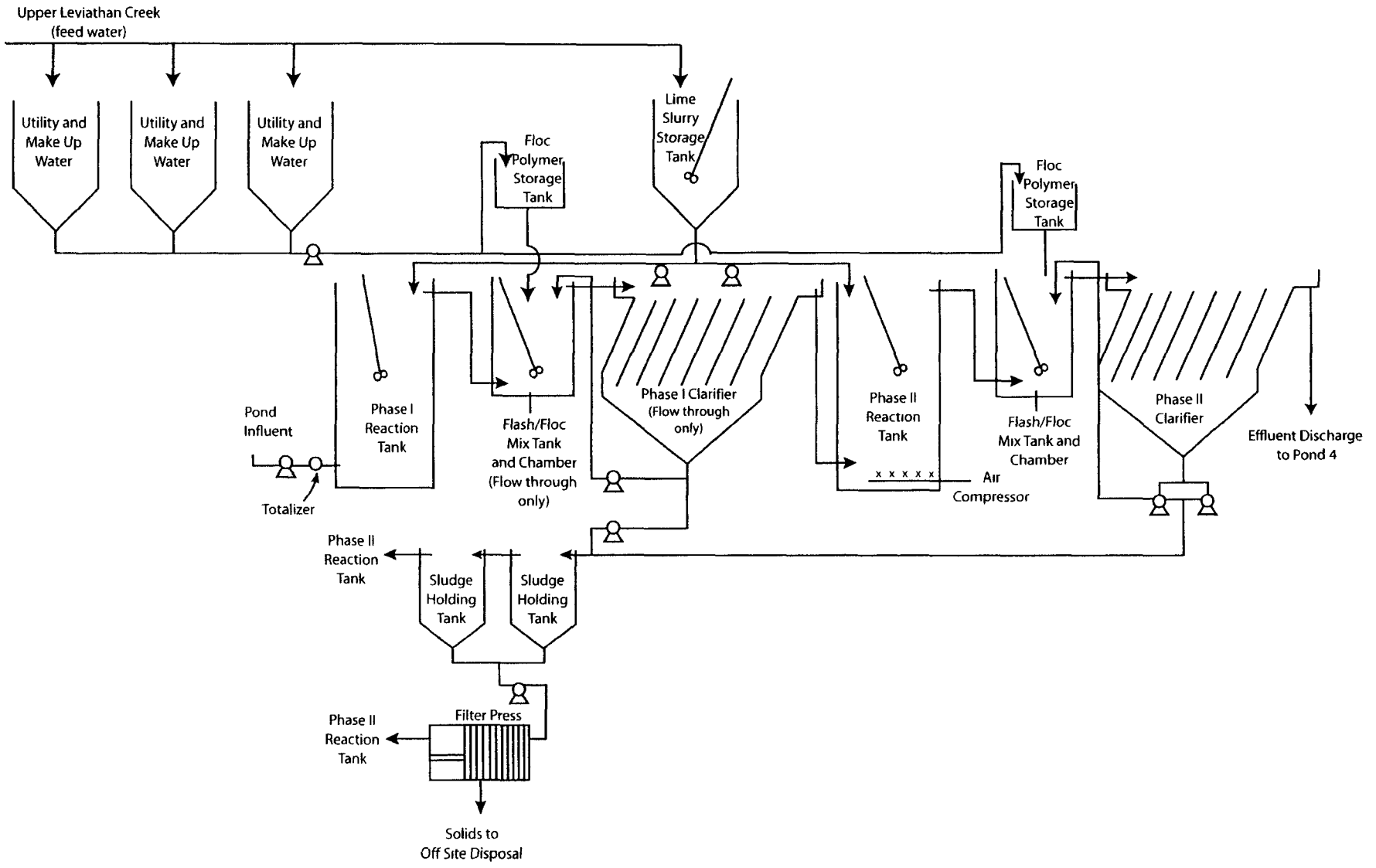

FIGURE 1-2. ACTIVE LIME TREATMENT SYSTEM MONOPHASIC SCHEMATIC

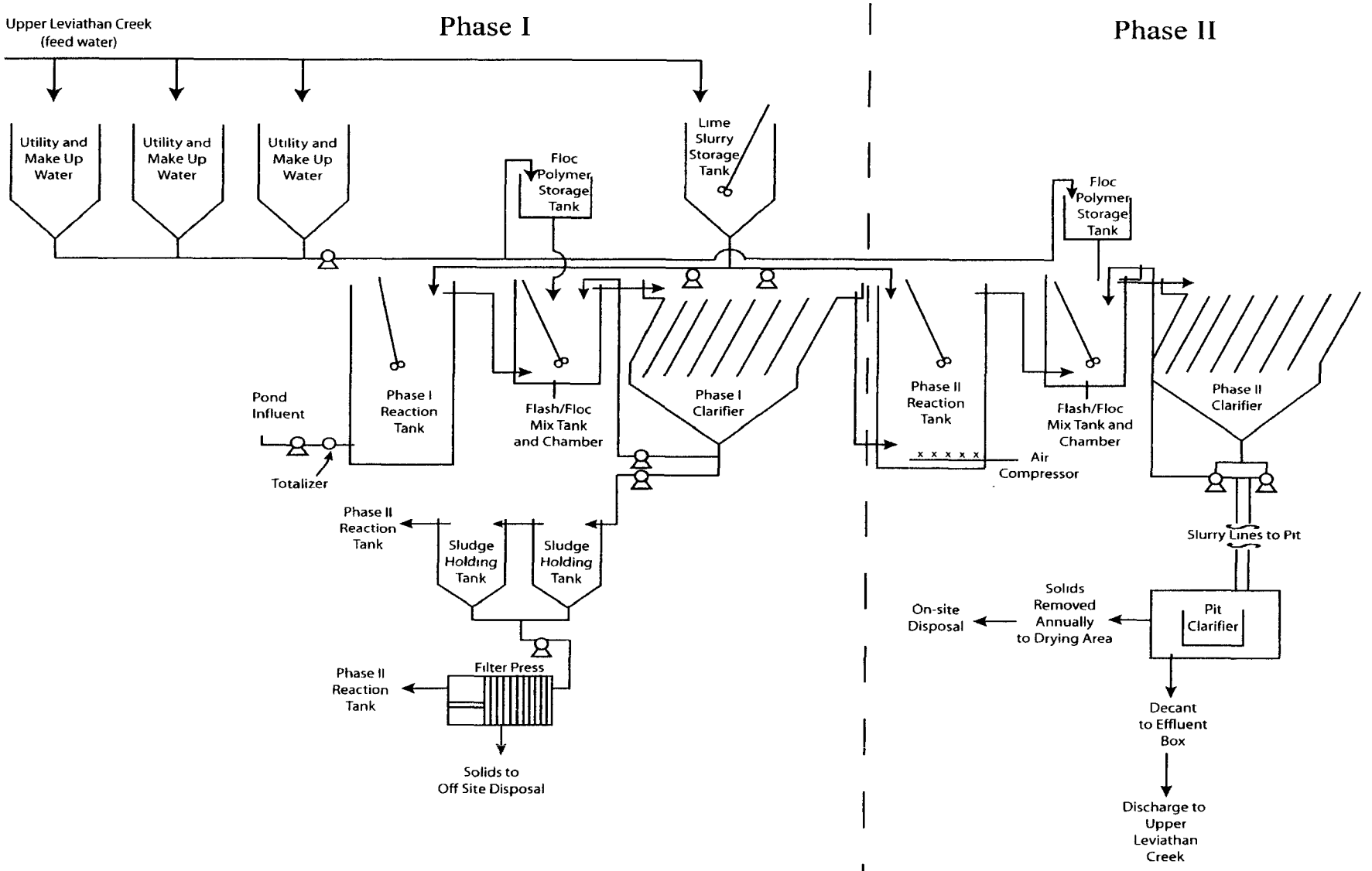

FIGURE 1-3 ACTIVE LIME TREATMENT SYSTEM BIPHASIC SCHEMATIC

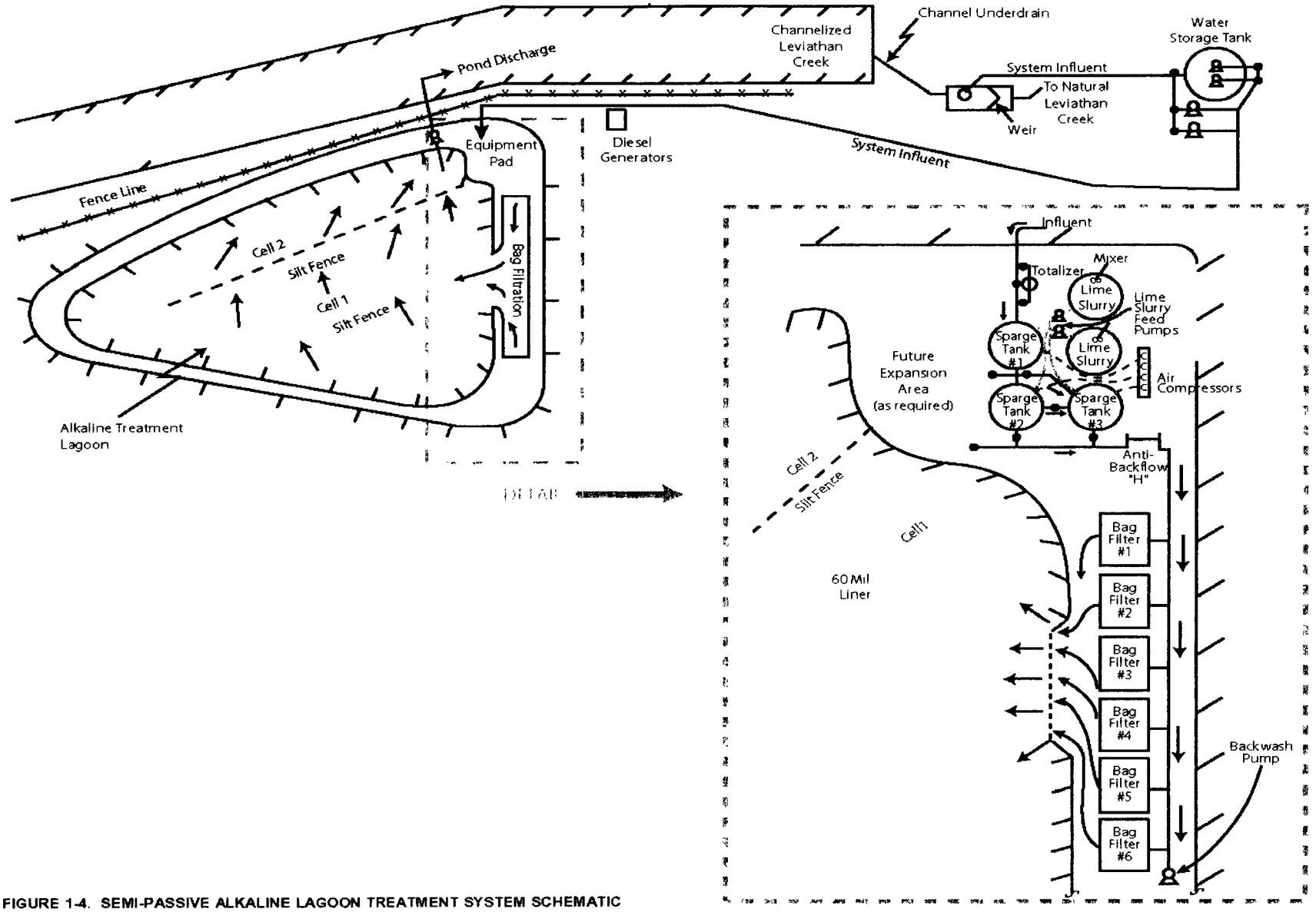

FIGURE 1-4. SEMI-PASSIVE ALKALINE LAGOON TREATMENT SYSTEM SCHEMATIC

discharge standards and the systems were not optimized for removal of these metals at such low concentrations. In the case of selenium in the AMD flow and selenium and cadmium in the ARD flow, removal efficiencies were not calculated because the influent and effluent metals concentrations were not statistically different.

The average and range of removal efficiencies for filtered influent and effluent samples collected from each lime treatment system during the evaluation period are presented in Tables 1-1 through 1-3. A summary of the average influent and effluent metals concentrations for each lime treatment system is also presented. The results of a comparison of the average effluent concentration for each metal to the EPA discharge standards is also presented; where a "Y" indicates that either the maximum concentration (based on a daily composite of three grab samples) and/or the average concentration (based on a running average of four daily composite samples) was exceeded; and an "N" indicates that neither discharge standard was exceeded.

The lime treatment process produced a large quantity of metal hydroxide sludge and filter cake. During operation in biphasic mode in 2002 and 2003, the active lime treatment system produced 43.8 dry tons of Phase I filter cake consisting mainly of iron and arsenic hydroxides and 211.6 dry tons of Phase II sludge consisting of metal hydroxides high in iron, aluminum, copper, nickel, and zinc. In addition, gypsum is also a component of the Phase II sludge. During operation in monophasic mode in 2002, the active lime treatment system produced 20.4 dry tons of filter cake consisting of metal hydroxides and gypsum. The semi-passive alkaline lagoon treatment system produced 12.6 dry tons of sludge consisting of metal hydroxides and gypsum. The solid waste residuals produced by the treatment systems were analyzed for hazardous waste characteristics. Total metals and leachable metals analyses were performed on the solid wastes for comparison to California and Federal hazardous waste classification criteria. The hazardous waste characteristics determined for the solid waste streams are presented in Table 1-4. The solid waste streams that were determined to be hazardous or a threat to water quality were transported to an off site TSD facility for disposal. Solid waste streams that passed both state and Federal hazardous waste criteria were disposed of in the mine pit.

1.6 Key Contacts

Additional information on this technology, the SITE Program, and the evaluation site can be obtained from the following sources:

EPA Contacts:

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Table 1-1. Active Lime Treatment System Removal Efficiencies: Biphasic Operation in 2002 and 2003

Target Metal	Number of Sampling Events	Average Influent Concentration (µg/L)	Standard Deviation	Average Effluent Concentration (µg/L)	Standard Deviation	Exceeds Discharge Standards (Y/N)	Average Removal Efficiency (%)	Range of Removal Efficiencies (%)
Primary Target Metals								
Aluminum	12/1	381,000	48,792	1,118	782	N	99.7	99.2 to 99.9
Arsenic	12/1	2,239	866	8.6	1.9	N	99.6	99.2 to 99.8
Copper	12/1	2,383	276	8.0	2.5	N	99.7	99.4 to 99.8
Iron	12/1	461,615	100,251	44.9	66.2	N	100	99.9 to 100
Nickel	12/1	7,024	834	34.2	15.4	N	99.5	99.2 to 99.9
Secondary Water Quality Indicator Metals								
Cadmium	12/1	54.4	6.1	0 70	0.28	N	98.7	97 5 to 99.4
Chromium	12/1	877	173	5.7	12.2	N	99.3	93.8 to 99.9
Lead	12/1	7.6	3.6	2 0	1.1	N	78.3	69.2 to 86.7
Selenium	12/1	4.3	3.9	3.8	1.5	N	NC	NC
Zinc	12/1	1,469	176	19.3	8.9	N	98.7	97.4 to 99.4

NC = Not calculated as influent and effluent concentrations were not statistically different
µg/L = Microgram per liter

Table 1-2. Active Lime Treatment System Removal Efficiencies: Monophasic Operation in 2003

Target Metal	Number of Sampling Events	Average Influent Concentration (µg/L)	Standard Deviation	Average Effluent Concentration (µg/L)	Standard Deviation	Exceeds Discharge Standards (Y/N)	Average Removal Efficiency (%)	Range of Removal Efficiencies (%)
Primary Target Metals								
Aluminum	7	107,800	6,734	633	284	N	99.5	99.0 to 99.8
Arsenic	7	3,236	252	6.3	3.5	N	99.8	99.7 to 99.9
Copper	7	2,152	46.4	3 1	1.5	N	99.4	99.0 to 99.7
Iron	7	456,429	49,430	176	130	N	100.0	99.9 to 100.0
Nickel	7	2,560	128	46.8	34.7	N	97.9	95.7 to 99.3
Secondary Water Quality Indicator Metals								
Cadmium	7	26.1	14.1	0.2	0.027	N	99.1	98.4 to 99 7
Chromium	7	341	129	3.0	3.8	N	99.0	95.6 to 99.8
Lead	7	6.2	3.6	1.6	1.3	N	74.6	48 3 to 89.8
Selenium	7	16.6	13.6	2 1	0.43	N	93.1	91.0 to 94.4
Zinc	7	538	28.9	5.6	3.6	N	98.9	97.7 to 99.6

µg/L = Microgram per liter

Table 1-3. Semi-Passive Alkaline Lagoon Treatment System Removal Efficiencies in 2002

Target Metal	Number of Sampling Events	Average Influent Concentration (µg/L)	Standard Deviation	Average Effluent Concentration (µg/L)	Standard Deviation	Exceeds Discharge Standards (Y/N)	Average Removal Efficiency (%)	Range of Removal Efficiencies (%)
Primary Target Metals								
Aluminum	8	31,988	827	251	160	N	99.2	98.0 to 99.5
Arsenic	8	519	21.9	5.8	3.2	N	98.9	97.6 to 99.5
Copper	8	13 5	2.5	5.5	2.0	N	58.3	27.7 to 74.5
Iron	8	391,250	34,458	148	173	N	100	99.9 to 100
Nickel	8	1,631	47.0	22.6	10.3	N	98.6	97.2 to 99.1
Secondary Water Quality Indicator Metals								
Cadmium	8	0.2988	0.0035	0.4	0.1	N	NC	NC
Chromium	8	19.3	2.0	2.3	0.9	N	88.5	83 1 to 92.3
Lead	8	5.1	1.2	1.7	0.8	N	66.4	37 7 to 78.9
Selenium	8	3.3	1.6	3.2	1.3	N	NC	NC
Zinc	8	356	6.6	14.2	8.6	N	96.0	90.6 to 98.2

NC = Not calculated as influent and effluent concentrations were not statistically different
µg/L = Microgram per liter

Table 1-4. Determination of Hazardous Waste Characteristics for Solid Waste Streams at Leviathan Mine

Treatment System	Mode of Operation	Operational Year	Solid Waste Stream Evaluated	Total Solid Waste Generated	TTLC Pass or Fail	STLC Pass or Fail	TCLP Pass or Fail	Waste Handling Requirement
Active Lime Treatment System	Biphasic	2002	Phase I Filter Cake	22 7 dry tons	F	F	P	Off-site TSD Facility
			Phase II Pit Clarifier Sludge	118 dry tons	P	P	P	On-site Disposal
		2003	Phase I Filter Cake	21.1 dry tons	F	P	P	Off-site TSD Facility
			Phase II Pit Clarifier Sludge	93.6 dry tons	P	F	P	On-site Storage
	Monophasic	2003	Filter Cake	20.4 dry tons	F	F	P	Off-site TSD Facility
Semi-Passive Alkaline Lagoon Treatment System		2002	Bag Filter Sludge	Estimated 12.6 dry tons	P	P	P	On-site Storage

STLC = Soluble threshold limit concentration
TTLC = Total threshold limit concentration
TSD = Treatment, storage, and disposal
TCLP = Toxicity characteristic leaching procedure

SECTION 2
TECHNOLOGY EFFECTIVENESS

The following sections discuss the effectiveness of the lime treatment technologies demonstrated at the Leviathan Mine site. The discussion includes a background summary of the site, descriptions of the technology process and the evaluation approach, a summary of field activities, and results of the evaluation.

2.1 Background

Leviathan Mine is a former copper and sulfur mine located high on the eastern slopes of the Sierra Nevada Mountain range, near the California-Nevada border. Intermittent mining of copper sulfate, copper, and sulfur minerals since the mid-1860s resulted in extensive AMD and ARD at Leviathan Mine. During the process of converting underground workings into an open pit mine in the 1950s, approximately 22 million tons of overburden and waste rock were removed from the open pit mine and distributed across the site. Oxidation of sulfur and sulfide minerals within the mine workings and waste rock forms sulfuric acid (H_2SO_4), which liberates toxic metals from the mine wastes creating AMD and ARD. AMD and ARD at Leviathan Mine contain high concentrations of toxic metals, including arsenic, and historically flowed directly to Leviathan Creek without capture or treatment.

2.1.1 Site Description

The Leviathan Mine property occupies approximately 102 hectares in the Leviathan Creek basin, which is located on the northwestern flank of Leviathan Peak at an elevation ranging from 2,134 meters to 2,378 meters above mean sea level. Access to the mine site is provided by unpaved roads (United States Forest Service Road 52) from State Highway 89 on the southeast and from US Highway 395 south of Gardnerville, Nevada, on the northeast. Of the total property, approximately 1 million square meters are disturbed by mine-related activities. With the exception of approximately 85 thousand square meters on Forest Service lands, mine-related workings are located on property owned by the State of California. Figure 2-1 presents a map showing the layout of the Leviathan Mine site.

The mine site lies within the Bryant Creek watershed and is drained by Leviathan and Aspen creeks, which combine with Mountaineer Creek 3.5 kilometers below the mine to form Bryant Creek, a tributary to the East Fork of the Carson River. The terrain in the Leviathan Creek basin includes rugged mountains and high meadowlands. The area has a climate typical of the eastern slope of the Sierra Nevada range characterized by warm dry summers with the bulk of the precipitation occurring as winter snow. Vegetation at the site is representative of the high Sierra Nevada floristic province, with scattered stands of mixed conifers or Jeffery pine on north-facing slopes. Aspen groves border parts of Leviathan and Aspen creeks, while shrub communities dominate flats and south facing slopes.

Precipitation in the area around Leviathan Mine varies with elevation and distance from the crest of the Sierra Nevada mountain range. The heaviest precipitation is from November through April. Annual precipitation on western slopes of the Sierras averages about 55 inches, varying from a low of about 20 inches to highs estimated in the range of 65 to 70 inches in some of the more remote mountain areas near the easterly boundary of Leviathan Creek basin. There is little precipitation data for the mine site; therefore, a mean annual precipitation was estimated at 27.8 inches per year using local weather monitoring stations provided by the U.S. Geological Survey (EMC^2 2004a). A large percentage of the precipitation which falls during the winter months occurs as snow. Snow pack accumulates from about November through March, with the maximum accumulation generally occurring about April 1. The average April 1 snow line is below an elevation of 1,525 meters. The snow pack generally begins to melt during March, but the period of major snowmelt activity is typically April through July. Winter snow pack is the source of about 50 percent of annual runoff.

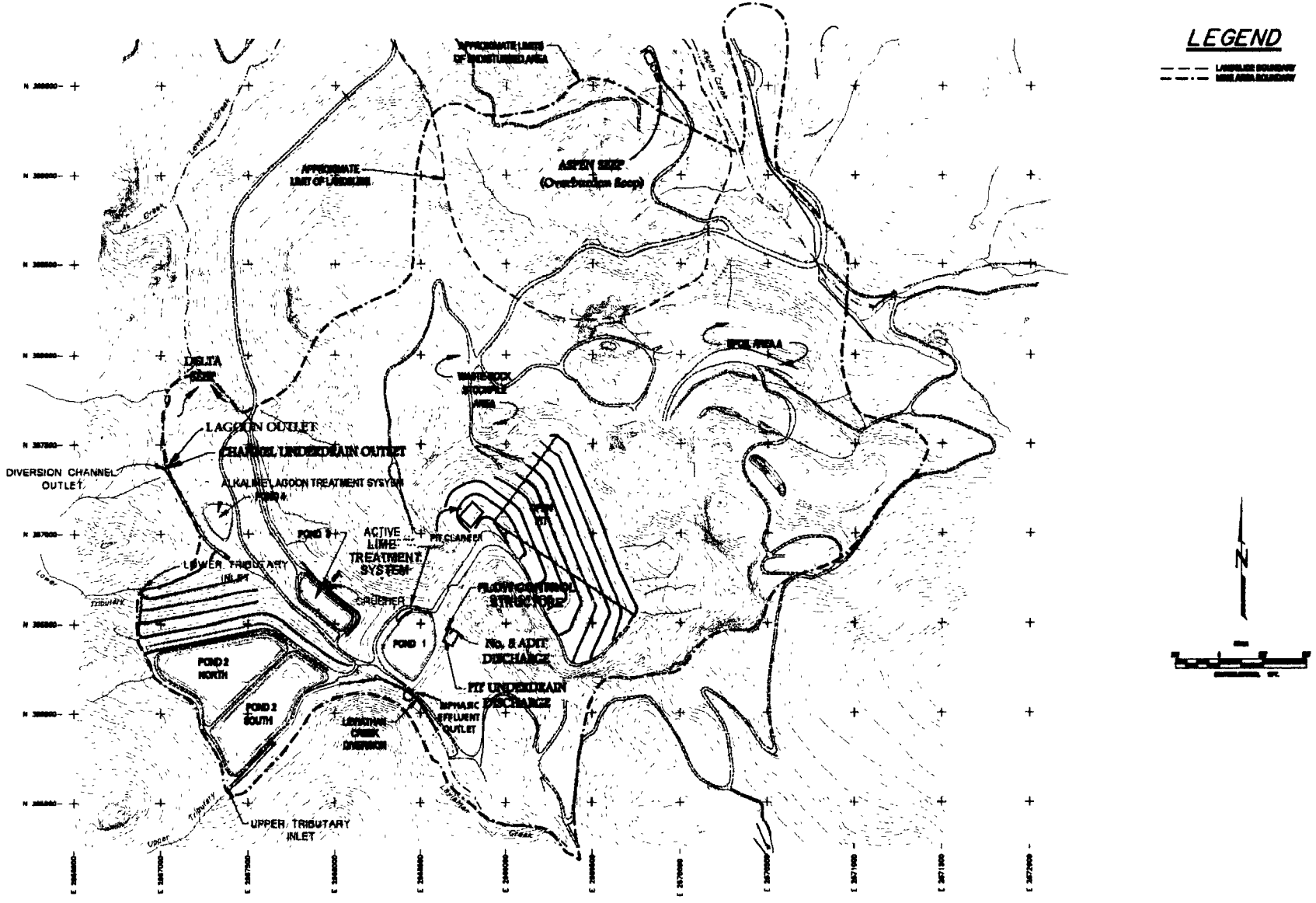

FIGURE 2-1. SITE LAYOUT

2.1.2 History of Contaminant Release

Prior to 1984, the various sources of AMD and ARD discharging from the Leviathan Mine site included AMD from the floor of the mine pit flowing west into Leviathan Creek; AMD from Adit No. 5, located below the mine pit, flowing west into Leviathan Creek; ARD from the Delta Area (also known as Delta Seep), located adjacent to Leviathan Creek along the western edge of the mine area, flowing northwest into Leviathan Creek; and ARD from Aspen Seep, located along the northern portion of the site within the overburden tailings piles, flowing north into Aspen Creek. Historically, the concentrations of five primary target metals, aluminum, arsenic, copper, iron, and nickel in the AMD and ARD released to Leviathan and Aspen creeks have exceeded EPA discharge standards up to 3,000 fold. Historical concentrations for each source of AMD and ARD are presented in Table 2-1.

When AMD was inadvertently released in large quantities from the Leviathan Mine site in the 1950s, elevated concentrations of toxic metals resulted in fish and insect kills in Leviathan Creek, Bryant Creek, and the east fork of the Carson River. The absence of trout among the fish killed in Bryant Creek and in the east fork of the Carson River immediately downstream from Bryant Creek indicated that continuous discharges from mining operations had eliminated the more sensitive trout fisheries that existed prior to open-pit operations. Various efforts were made between 1954 and 1975 to characterize the impacts of Leviathan Mine on water quality at and below the site during and after open-pit mining operations (California Regional Water Quality Control Board – Lahontan Region [RWQCB] 1995).

2.1.3 Previous Actions

The Leviathan Mine Pollution Abatement Project was initiated by the state of California in 1979 with the preparation of a feasibility study. In 1982, the State contracted the design of the Pollution Abatement Program, which was then implemented in 1984 with physical actions that significantly reduced the quantity of toxic metals discharging from the mine site. Work conducted at the site included regrading over-burden piles to prevent impounding and infiltration of precipitation and promote surface runoff; partially filling and grading the open pit; constructing a surface water collection system within the reworked mine pit to redirect uncontaminated surface water to Leviathan Creek; constructing a pit under drain (PUD) system beneath the pit (prior to filling and grading) to collect and divert surface water seeping into the pit floor; construction of five storage/evaporation ponds to collect discharge from the PUD, Delta Seep, and Adit No. 5; and rerouting Leviathan Creek by way of a concrete diversion channel to minimize contact of creek water with waste rock piles. During pond construction, previously unrecognized springs were encountered. To capture the subsurface flow from these springs, a channel under drain (CUD) was constructed beneath Leviathan Creek (RWQCB 1995).

Starting in 1997, EPA initiated enforcement actions at the Leviathan Mine site to further mitigate potential releases of AMD and ARD from the various sources. In response to EPA's 1997 action memorandum, the state of California implemented the active lime treatment system in 1999 to treat AMD that collects in the retention ponds. Since the installation of the active lime treatment system in 1999, no releases of AMD have occurred from the retention ponds to Leviathan Creek. Between 2000 and 2001, EPA initiated further actions with three additional action memoranda. In response to EPA's July 21, 2001, action memorandum, ARCO implemented the semi-passive alkaline lagoon treatment system to treat ARD from the CUD. Figure 2-1 presents a detailed site map of the mine site as it exists in 2004, after implementation of the lime treatment systems and other physical work conducted at the mine site.

In 2002, EPA prepared an additional action memorandum setting final discharge standards for the five primary target metals and five secondary water quality indicator metals for discharge of treated water from the treatment systems to Leviathan Creek (EPA 2002). Discharge standards for the five primary metals of concern are presented in Table 2-1. The maximum daily standard equals the highest concentration of a target metal to which aquatic life can be exposed for a short period of time without deleterious effects. The four-day average standard equals the highest concentration of a target metal to which aquatic life can be exposed for an extended period of time (4 days) without deleterious effects.

2.2 Process Description

Each lime treatment system evaluated at Leviathan Mine was set up to treat a specific AMD, ARD, or combined AMD/ARD flow captured at the mine site. Operated in monophasic mode, the active lime treatment system was evaluated for its ability to treat a combined moderate ARD/AMD flow from Adit No.5, CUD, and Delta Seep sources of about 250 liters per minute (L/min), without regard to metals species or concentrations in the source. Operated in biphasic mode, the active lime treatment system was evaluated for its ability to treat a high AMD flow from the retention ponds of about 720 L/min where arsenic concentrations were high enough to generate a hazardous solid waste stream. The alkaline lagoon treatment system was evaluated for its ability to treat a low ARD flow from the CUD of about 120 L/min with relatively low metals content. Each treatment system was optimized for flow rate and target metals precipitation based on the source being treated. The following sections describe the processes for each treatment system.

Table 2-1. Summary of Historical Metals of Concern

Analyte	Number of Samples	Detection Percentage	Minimum Concentration (mg/L)	Maximum Concentration (mg/L)	Mean (mg/L)	Standard Deviation (mg/L)	Discharge Standards	
							Maximum (a) (mg/L)	Average (b) (mg/L)
Adit No. 5								
Aluminum	46	100	220	430	310.4	63.61	4.0	2.0
Arsenic	45	100	8.6	28	16.24	5.454	0.34	0.15
Copper	28	100	0.88	4.2	1.503	0.965	0.026	0.016
Iron	45	100	120	2,400	815.1	368.7	2.0	1.0
Nickel	46	100	4.4	10	6.113	1.624	0.84	0.094
Combination of Ponds 1, 2 North, and 2 South								
Aluminum	29	100	3	4,900	1,198.9	1,036.2	4.0	2.0
Arsenic	27	100	0.192	92	27.05	19.88	0.34	0.15
Copper	9	100	2.4	35	8.133	10.19	0.026	0.016
Iron	32	100	4	6,600	1,733.9	1,449.7	2.0	1.0
Nickel	27	100	1.2	61	17.50	11.96	0.84	0.094
Channel Under Drain								
Aluminum	60	100	29	68	48.03	10.64	4.0	2.0
Arsenic	61	100	0.091	0.80	0.447	0.191	0.34	0.15
Copper	37	97.3	0	0.13	0.026	0.035	0.026	0.016
Iron	61	100	270	460	367	59.16	2.0	1.0
Nickel	61	100	0.21	3.4	1.947	0.791	0.84	0.094
Aspen Seep								
Aluminum	34	100	0.073	65	50.86	14.17	4.0	2.0
Arsenic	34	97.1	0	0.1	0.028	0.027	0.34	0.15
Copper	21	95.2	0	1.8	1.294	0.549	0.026	0.016
Iron	34	100	0.11	580	123.9	113.2	2.0	1.0
Nickel	34	97.1	0	0.75	0.554	0.181	0.84	0.094
Delta Seep								
Aluminum	18	100	0.89	4.7	1.68	0.879	4.0	2.0
Arsenic	19	84.2	0.052	0.094	0.067	0.012	0.34	0.15
Copper	17	35.3	0.0018	0.14	0.0324	0.054	0.026	0.016
Iron	19	100	18.0	33.0	21.5	3.93	2.0	1.0
Nickel	18	100	0.41	0.563	0.493	0.051	0.84	0.094

(a) Based on a daily composite of three grab samples
(b) Based on the average of four daily composite samples
mg/L = Milligram per liter

2.2.1 Active Lime Treatment System

Influent to the active lime treatment system consists of AMD pumped out of retention ponds 1, 2 north, and 2 south. In the biphasic mode (Figure 1-2), influent is pumped from Pond 1 at a flow rate of up to 720 L/min into the 40,000 liter Phase 1 reaction tank. Forty-five percent lime slurry is then added at up to 1.3 L/min to raise the pH to approximately 2.8 to 3.0. In this pH range, a portion of the dissolved ferrous iron is oxidized to ferric iron and precipitates out of solution (as ferric hydroxide) along with the majority of dissolved arsenic. Process water was drawn from upper Leviathan Creek to make up the lime slurry used in the treatment process. The process solution then flows to a 4,000 liter flash/floc mixing tank where a polymer flocculent is added to promote growth of ferric iron hydroxide and adsorbed arsenic floc. The process solution then flows into the 40,000 liter Phase I clarifier for floc settling and thickening. Supernatant from the Phase I clarifier flows into the Phase II reaction tank for additional lime treatment of remaining acidity and target metals. The thickened ferric iron hydroxide and arsenic solids are periodically pumped from the bottom of the Phase I clarifier into sludge holding tanks, and then into a 550 liter-capacity batch filter press for dewatering. The small volume of arsenic-laden Phase I filter cake is disposed of as a hazardous waste at an off site TSD facility. Supernatant from the sludge holding tanks and filtrate from the filter press are pumped to the Phase II reaction tank for additional treatment. The total

hydraulic residence time (HRT) for Phase I of the active lime treatment system is about 2 hours at maximum flow rate.

To complete the precipitation of metals during biphasic operation, the pH of the process solution in the 40,000 liter Phase II reaction tank is raised to approximately 7.9 to 8.2 by adding up to 2.3 L/min of forty-five percent lime slurry. The process solution then flows to a 4,000 liter flash/floc mixing tank where a polymer flocculent is added to promote growth of the metal hydroxide floc. The process solution then flows into a 40,000 liter Phase II clarifier. The partially thickened precipitate is pumped from the bottom of the Phase II clarifier uphill to the 3.1 million liter pit clarifier, located within the mine pit, for extended settling. Supernatant from the pit clarifier that meets the discharge standards is released by gravity flow to Leviathan Creek. If the supernatant from the pit clarifier does not meet discharge standards, it is returned to Pond 1 for additional treatment. The non-hazardous metals-laden precipitate is removed from the pit clarifier annually, dewatered and air dried, and disposed of on site. The total HRT for Phase II of the active lime treatment system is about 3 to 6 days.

The active lime treatment system operated in the monophasic mode (Figure 1-3) utilizes the same process equipment as the system operated in biphasic mode; however, the precipitation process results in a single "output stream" of metals-laden precipitate that is thickened in the Phase II clarifier and dewatered using the batch filter press. Other changes include a lower influent flow rate of up to 250 L/min (due to HRT and thickening limitations of the Phase II clarifier), a lower lime dosage rate (0.35 L/min of forty-five percent lime slurry), and a difference in the makeup of the source water. The source water was comprised of a mixture of low-arsenic content ARD (50 percent from the CUD and 17.6 percent from Delta Seep) and high-arsenic content AMD (32.4 percent from Adit No.5). Because of the elevated arsenic concentrations in the source water, the resulting filter cake from operation of the active lime treatment system in monophasic mode exceeds State hazardous waste criteria and must be disposed of at an off site TSD facility.

2.2.2 Semi-Passive Alkaline Lagoon Treatment System

ARCO first tested the alkaline lagoon treatment system in 2001 for treatment of ARD recovered from the CUD. During operation of the alkaline lagoon treatment system (Figure 1-4), the ARD from the CUD is pumped to the head of the alkaline lagoon treatment system, which is located on a high density polyethylene (HDPE)-lined treatment pad along the north berm of the treatment lagoon. The influent is pumped uphill from the CUD at a flow rate up to 120 L/min into three 4,000 liter lime contact reactors; the reactors have a combined HRT of 1 hour and 40 minutes at maximum flow rate. Forty-five percent lime slurry is added to each of the lime contact reactors (combined dosage rate of 0.16 L/min) to raise the pH to about 8.0. Process water was drawn from upper Leviathan Creek to make up the lime slurry used in the treatment process. The reactors are sparged with compressed air to provide vigorous mixing of the lime/ARD solution. Air sparging also helps to oxidize ferrous iron to ferric iron, which reduces lime demand. During sparging, metal hydroxide floc forms within the reaction tanks. The process solution then flows by gravity through a series of six 5- by 5-meter spun fabric bag filters to remove the metal hydroxide floc.

The bag filtration process relies on the build up of filter cake on the inside of each bag to remove progressively smaller floc particles. Effluent from the bag filters, including soluble metals, unreacted lime, and floc particles too small to be captured, flows by gravity into the 5.4 million liter multi-cell settling lagoon. The settling lagoon is divided into two sections using an anchored silt fence. Unsettled solids are captured on the silt screen between the two cells. The settling lagoon typically provides a HRT of 415 hours at a flow rate of 120 L/min. This extended residence time facilitates contact of any remaining dissolved metals with unreacted lime. Effluent from the settling lagoon that meets EPA discharge standards is periodically discharged to Leviathan Creek. The non-hazardous precipitate captured in the bag filters and settled in the lagoon is periodically recovered and stored on site.

2.3 Evaluation Approach

Evaluation of the lime treatment technologies occurred between June 2002 and October 2003, separated by winter shutdown. During the evaluation period, multiple sampling events were conducted for each of the treatment systems in accordance with the 2002 and 2003 Technology Evaluation Plan/Quality Assurance Project Plans (TEP/QAPP) (Tetra Tech 2002 and 2003). During each sampling event, EPA collected metals data from each systems' influent and effluent streams, documented metals removal and reduction in acidity within each systems' unit operations, and recorded operational information pertinent to the evaluation of each treatment system. The treatment systems were evaluated independently, based on removal efficiencies for primary and secondary target metals, comparison of effluent concentrations to EPA-mandated discharge standards, and on the characteristics of and disposal requirements for the resulting metals-laden solid wastes. Removal efficiencies of individual unit operations were also evaluated. The following sections describe in more detail the project objectives and sampling program.

2.3.1 Project Objectives

As discussed in the TEP/QAPPs (Tetra Tech 2002 and 2003), two primary objectives identified for the SITE demonstration were considered critical to the success of the lime treatment technology evaluation. Five secondary objectives were identified to provide additional information that is useful, but not critical to the technology evaluation. The primary objectives of the technology evaluations were to:

- Determine the removal efficiencies for primary target metals over the evaluation period
- Determine if the concentrations of the primary target metals in the treated effluent are below the discharge standards mandated in 2002 Action Memorandum for Early Actions at Leviathan Mine (EPA 2002)The following secondary objectives also were identified:
- Document operating parameters and assess critical operating conditions necessary to optimize system performance
- Monitor the general chemical characteristics of the AMD or ARD water as it passes through the treatment system
- Evaluate operational performance and efficiency of solids separation systems
- Document solids transfer, dewatering, and disposal operations
- Determine capital and operation and maintenance costs

2.3.2 Sampling Program

Over the duration of the demonstration, EPA collected pretreatment, process, and post-treatment water samples from each lime treatment system. These samples were used to evaluate the primary and secondary objectives, as identified in the TEP/QAPPs (Tetra Tech 2002 and 2003). Sludge samples also were collected to document the physical and chemical characteristics of the sludge and to estimate the volume and rate of sludge generation by each treatment technology. Summary tables documenting the water and sludge samples collected and the analyses performed for each lime treatment system are presented in Appendix A. In addition to chemical analyses performed on the samples collected, observations were recorded on many aspects of the operations of each treatment system. The sampling program is summarized below by objective.

Primary Objective 1: Determine the removal efficiency for each metal of concern over the demonstration period. To achieve this objective, influent and effluent samples from each treatment system were collected from strategic locations within the treatment systems. The samples were filtered, preserved, and then analyzed for primary target metals: aluminum, arsenic, copper, iron, and nickel and secondary water quality indicator metals: cadmium, chromium, lead, selenium, and zinc. When possible, effluent samples were collected approximately one HRT after the influent samples were collected. However, because the HRT of the different treatment systems ranged from hours to days and changed with operational conditions, it was not always practical to implement such a time-separated pairing procedure. From the influent and effluent data collected, overall average removal efficiencies were calculated for each target metal over the period of the demonstration. The results of the removal efficiency calculations are summarized in Section 2.5.1.

Primary Objective 2: Determine if the concentration of each target metal in the treated effluent is below the EPA discharge standard. Results from effluent samples collected to meet Primary Objective 1 were used to meet this objective. The sampling schedule was designed so that a composite of three grab samples were collected on each sampling day. Results from daily composite samples were compared against EPA's daily maximum discharge standards (EPA 2002). In addition, 4-day running averages were calculated for each target metal for comparison against EPA's four-day average discharge standards. To determine if the discharge standards were met, the effluent data were compared directly to the applicable standards as specified in Table 2-1. In addition, a statistical analysis was performed to determine whether or not statistically the results were below the discharge standards. The results of the comparison of effluent data to discharge standards are summarized in Section 2.5.2.

Secondary Objective 1: Document operating parameters and assess critical operating conditions necessary to optimize system performance. To achieve this objective, system flow rate data, chemical dosing and aeration rate data, and contact and mixing time data were recorded by the system operators and the SITE demonstration sampling team. The performance of individual unit operations was assessed by determining the reduction in target metal concentrations along each treatment system flow path. A description of system operating parameters and discussion of metals reduction within individual unit operations are presented in Sections 2.5.3 and 2.5.4 for the active lime treatment system and semi-passive alkaline lagoon treatment system, respectively.

Secondary Objective 2: Monitor the general chemical characteristics of the AMD or ARD water as it passes through the treatment system. To achieve this objective, the influent and effluent samples collected to meet Primary Objectives 1 and 2 were analyzed for total iron, sulfate, total suspended solids (TSS), total dissolved solids (TDS), and total and bicarbonate alkalinity. Field measurements were also collected for ferrous iron, sulfide, pH, dissolved oxygen (DO), temperature, oxidation-reduction potential (ORP), and conductivity. A discussion of these data and associated reaction chemistry for the active lime treatment system and semi-passive alkaline lagoon treatment system are presented in Sections 2.5.3 and 2.5.4, respectively.

Secondary Objective 3: Evaluate operational performance and efficiency of solids separation systems. To achieve this objective, influent, intermediate, and effluent samples were collected from the solids separation systems of each treatment system. The samples were analyzed for filtered and unfiltered metals, TSS, and TDS to assess target metal removal

efficiencies, solids removal rates and efficiencies, HRT, and residual levels of solids in the effluent streams.

The results of this evaluation for the active lime treatment system and semi-passive alkaline lagoon treatment system are presented in Sections 2.5.3 and 2.5.4, respectively.

Secondary Objective 4: Document solids transfer, dewatering, and disposal operations. To achieve this objective, the system operators maintained a log of the volume and rate of solids transferred from the solids separation systems for dewatering and disposal. Solids samples were collected after dewatering and analyzed for residual moisture content and total and leachable metals to determine waste characteristics necessary to select an appropriate method of disposal. Leachable metals were evaluated using the California Waste Extraction Test (WET) (State of California 2004), the Method 1311: Toxicity Characteristic Leaching Procedure (TCLP) (EPA 1997), and Method 1312: Synthetic Precipitation and Leaching Procedure (SPLP) (EPA 1997). An evaluation of solids handling for each treatment system is presented in Section 2.5.5.

2.4 Field Evaluation Activities

The following sections discuss activities required to conduct a technical evaluation of each treatment technology at the Leviathan Mine site. The discussion includes a summary of mobilization activities, operation and maintenance activities, process modifications, evaluation monitoring activities, demobilization activities, and lessons learned.

2.4.1 Mobilization Activities

The active lime treatment system was constructed in 1999 and was in operation for three years prior to technology evaluation activities. Therefore, mobilization activities were limited to system reassembly and shakedown conducted in the spring, after winter shutdown. Mobilization activities typically require a three week period and include the following:

- Removal of previous year's sludge accumulation from the pit clarifier and disposal on site as a non-hazardous waste.
- Pressure washing of gypsum coating on reaction tanks and lamella clarifiers.
- Pipe and hose lay out and assembly.
- Modifications to source water capture and delivery system and effluent discharge system.
- System filling, pressure testing, and leak repair.
- Removal of precipitation from fuel storage secondary containment units.
- Delivery and setup of site support equipment, supplies, and chemical reagents

The alkaline lagoon was constructed in 2001 and was in operation for one year prior to technology evaluation activities. Therefore, mobilization activities were limited to system reassembly and shakedown conducted in the spring, after winter shutdown. Mobilization activities typically require a two week period and include the following:

- Removal of bag filters containing previous year's sludge accumulation and placement in roll-off bins for off site disposal as a non-hazardous waste.
- Pipe and hose lay out and assembly.
- Capture of Delta Seep and modification of the CUD delivery system to include water from Delta Seep.
- Repair of liner underlying treatment system.
- System filling, pressure testing, and leak repair.
- Removal of precipitation from fuel storage secondary containment units.
- Delivery and setup of site support equipment, supplies, and chemical reagents.

2.4.2 Operation and Maintenance Activities

The following sections discuss operation and maintenance activities documented during the evaluation of each treatment technology. The discussion includes a summary of each system's startup and shutdown dates, treatment and discharge rates, problems encountered, quantity of waste treated, reagents consumed, process waste generated, and percentage of time each system was operational.

2.4.2.1 Active Lime Treatment System

The active lime treatment system was operated in the biphasic mode in 2002, and in both the biphasic and monophasic modes in 2003. A description of system operation and maintenance activities for each mode of operation is presented below.

Biphasic Operations. During the 2002 treatment season, the system began treating pond water on July 10, 2002. By July 18, 2002, up to 700 L/min of AMD was being treated. Treatment rates ranged from 390 to 700 L/min. On July 22, effluent began discharging from the pit clarifier to Leviathan Creek. Discharge rates ranged from 290 to 460 L/min. The system was shut down on August 1, due to a low lime supply and clogs in the delivery system. The lime storage tanks and delivery lines were flushed out and operations resumed on August 6. On August 8, 2002 a pH probe in the Phase II reaction tank was found to be out of calibration and was replaced. On August 15, 2002 the pipelines carrying treated slurry up to the pit clarifier were found to be constricted with gypsum precipitate, reducing the system treatment rate. The pipes were replaced to alleviate flow constrictions. Treatment of pond water was completed on September 24, 2002. During 2002, the system treated 14.7 million liters of AMD using

75 dry tons of lime and generated 22.7 dry tons of hazardous solids and 118 dry tons of non-hazardous solids. The system was operational approximately 84 percent of the time during the 2002 treatment season. The system was operated 16 hours per day, during two shifts, each shift staffed by an operator and a helper.

During the 2003 treatment season, the system began treating pond water on July 28, 2003. Treatment rates ranged from 620 to 700 L/min. On July 31, effluent began discharging from the pit clarifier to Leviathan Creek. Discharge rates ranged from 230 to 930 L/min. The system was shut down on August 1 due to a viscous lime supply limiting the function of the lime delivery system. Solidified lime was cleaned out of the storage tanks, new lime was delivered, and operations resumed on August 3. On August 5, a pH probe in the Phase II reaction tank was found to be out of calibration and was replaced. On August 6, minor polymer feed adjustments were required during night time operations, potentially due to cool overnight temperatures. Treatment of pond water was completed on August 14, 2003. During 2003, the system treated 13.6 million liters of AMD using 49.6 dry tons of lime and generated 21.1 dry tons of hazardous solids and 93.6 dry tons of non-hazardous solids. The system was operational approximately 95 percent of the time during the 2003 treatment season. The system was operated 24 hours per day, during three shifts, each shift staffed by an operator and a helper.

Monophasic Operations. During the 2003 treatment season, the system began treating combined flows from the CUD, Delta Seep, and Adit No. 5 on June 18, 2003. Treatment rates ranged from 220 to 250 L/min. System effluent was discharged to Pond 4, in case of system upset, prior to batch discharge to Leviathan Creek. On June 25 and July 14, effluent was pumped out of Pond 4 and into Leviathan Creek. Batch discharge occurred over a 3 to 4 day period at flow rates of 500 to 890 L/min. Monophasic treatment of combined flows from the CUD, Delta Seep, and Adit No. 5 was discontinued on July 20, 2003 to begin treatment of pond water under biphasic operational conditions. During 2003, the system treated 17.4 million liters of combined AMD and ARD using 23.8 dry tons of lime and generated 20.4 dry tons of hazardous solids. The system was operational approximately 96 percent of the time during the 2003 treatment season. The system was operated 24 hours per day, during three shifts, each shift staffed by an operator and a helper.

2.4.2.2 Semi-passive Alkaline Lagoon Treatment System

During the 2002 treatment season, the semi-passive alkaline lagoon treatment system began treating combined flows from the CUD on June 26, 2002. Treatment rates ranged from 62 to 120 L/min. On June 27, the aeration system in each reaction tank was modified to increase aeration efficiency. The bag filters required one day to build up a sufficient layer of cake to adequately filter floc from solution. Treated water in the lagoon was recirculated to homogenize higher pH water discharged to the lagoon during startup.

System effluent was periodically batch discharged from the lagoon to Leviathan Creek. On July 25, system discharge was temporarily suspended because the silt curtains separating the two cells within the lagoon became clogged. Water was not flowing readily through the silt curtain when effluent was discharged from Cell 2, causing strain on the barriers. The silt curtain between Cells 1 and 2 was cleaned to increase flow, and system discharge resumed by the afternoon. A similar problem occurred and was resolved on August 15. System effluent was also discharged from the lagoon to Leviathan Creek on September 4, September 23, and October 15, 2002. Batch discharge generally occurred over a 2 to 3 day period at flow rates of 320 to 430 L/min.

Between July 27 and July 28, the pipe carrying partially treated slurry between Reaction Tank No. 1 and No. 2 became clogged. Partially treated slurry from Reaction Tank No. 1 overflowed and spilled into the lagoon. Excess lime was added to the treatment system to increase lagoon pH, and water was re-circulated in the lagoon to balance pH and facilitate precipitation. On October 10, a lime delivery line broke, spilling approximately 1,950 liters of lime onto the treatment system pad and into the lagoon. Treated water was recirculated in the lagoon to balance the pH in the lagoon. Treatment was discontinued on November 1, 2002 due to freezing and breaking of system piping. During 2002, the system treated 12.3 million liters of ARD using 19.4 dry tons of lime and generated 12.6 dry tons of non-hazardous solids. The system was operational approximately 89 percent of the time during the 2002 treatment season. The system was operated 24 hours per day; however, minimal staffing was required for operation. Staff operating the active lime treatment system conducted at least hourly checks on the system.

2.4.3 Process Modifications

The following sections discuss process modifications documented during the evaluation of each treatment technology.

2.4.3.1 Active Lime Treatment System

A number of modifications were made to the Active Lime Treatment System to alleviate problems encountered during operations. The majority of the modifications were made to alleviate problems related to lime delivery and process control.

Process modifications enacted during biphasic operations included:

- New lime delivery pumps designed to handle solids more efficiently were installed. However, the new

pumps did not completely solve the lime clogging problem.

- Flocculent was injected into the lines carrying slurry from the Phase II clarifier to the pit clarifier. The addition of flocculent after the Phase II clarifier reduced sludge build-up in the clarifier and increased operating efficiency. Because of restrictions due to scale buildup, an additional pipeline was installed to carry treated slurry from the Phase II clarifier to the pit clarifier. The addition of the new 4-inch diameter pipeline significantly increased flow capacity to the pit clarifier.

Process modifications enacted during monophasic operations included:

- In an effort to decrease lime consumption and improve precipitate growth, a sludge recirculation system was constructed. The system was designed to collect a fraction of the sludge from the Phase II clarifier, and re-circulate the sludge (generally 3 percent solids and 97 percent water) into the reaction tank. Excess alkalinity and "seed" solids in the re-circulated sludge increased reaction efficiency, reduced lime consumption, and improved particulate settling in the Phase II clarifier.
- Lime was added to Reaction Tank No. 1 to allow a longer period for lime dissolution and reaction with metals, reducing overall lime requirement and treatment system scaling.

2.4.3.2 Semi-passive Alkaline Lagoon Treatment System

A number of modifications were made to the semi-passive alkaline lagoon treatment system to alleviate problems encountered during operations. The majority of the modifications were made to alleviate problems related to aeration and lime delivery and process control. Process modifications implemented included:

- New aerators were installed in the reaction tanks to increase aeration rate and mixing.
- The lime delivery system was modified on July 9, 2002, to supply lime automatically based on the pH in Reaction Tank No.1, rather than at a specified delivery rate. The pH-based system, similar to that used on the active lime treatment system, operated more effectively with minor variations observed in the CUD flow rate and chemistry.

2.4.4 Evaluation Monitoring Activities

The following sections discuss monitoring activities conducted during the evaluation of each treatment technology. The discussion includes a summary of sampling dates and locations for system performance, unit operations, solids handling, and solids disposal samples outlined in the sampling program (see Section 2.3.2). Summary tables documenting the water and sludge samples collected and the analyses performed for each lime treatment system are presented in Appendix A.

2.4.4.1 Active Lime Treatment System

The active lime treatment system was operated in the biphasic mode in 2002, and in both the biphasic and monophasic modes in 2003. A description of evaluation monitoring activities for each mode of operation is presented below.

Biphasic Evaluation Monitoring Activities. Both system performance and unit operations sampling was performed in 2002. System performance samples were collected from the system influent and effluent on July 18, 23, 25, and 30, August 1, 8, 15, 20, 22, 27, and 29, and September 4, 2002. Unit operations samples of the Phase I reaction tank effluent, Phase II reaction tank effluent, Phase II reaction tank influent, pit clarifier influent, and sludge tank overflow were collected on August 20, 2002. Solids handling samples of the pit clarifier sludge, filter press effluent, and filter cake were collected on August 27, 2002.

Limited monitoring was performed in 2003. Samples were collected from the system influent and effluent, Phase I reaction tank effluent, Phase II reaction tank effluent, Phase II reaction tank influent, Phase II clarifier settled solids, filter press decant, filter cake, Phase I flash/floc tank, Phase II flash/floc tank, and Phase I clarifier settled solids on August 12, 2003.

Monophasic Evaluation Monitoring Activities. System performance samples were collected from the system influent and effluent on June 24 and 26, and July 1, 3, 9, 10, and 16, 2003. An effluent sample was collected from Pond 4 prior to batch discharge on July 10, 2003. Unit operations samples of the Phase I reaction tank effluent, Phase II reaction tank influent, Phase II reaction tank effluent, Phase II clarifier influent, Phase II clarifier settled solids, and filter cake were collected on July 3, 2003. Solids handling samples of the Phase I clarifier settled solids, filter press decant, Phase II clarifier influent, and Phase II clarifier settled solids were collected on July 10, 2003.

2.4.4.2 Semi-passive Alkaline Lagoon Treatment System

System performance samples were collected from the system influent and effluent on July 18, 23, 25, and 30, and August 1, 6, 8, and 13, 2002. Water samples were collected from lagoon Cell No.1 and Cell No. 2 on July 30, 2002, to evaluate particulate settling. Samples of the bag filter influent and bag filter effluent were collected on July 23 and 30, and August 6 and 13, 2002, to evaluate solids filtration. A sludge sample

was collected from bag filter No. 1 on August 27, 2002, for waste characterization.

2.4.5 *Demobilization Activities*

Both treatment systems have been permanently constructed at Leviathan Mine and are winterized at the end of the treatment season to prevent damage during freezing conditions. Therefore, demobilization activities were limited to system disassembly and storage.

Demobilization activities required for the active lime treatment system typically occur over a three week period and include:

- Draining untreated and partially treated AMD from the reaction tanks, clarifiers, pumps, and lines back into the AMD pond.
- Cleaning solids and scale from the interior of the reaction tanks, lime slurry tank, and clarifiers.
- Discharging treated water from the pit clarifier to Leviathan Creek.
- Draining makeup water from the storage tank into the AMD pond.
- Draining and cleaning flocculent and lime from the feed pumps and lines.
- Storing flocculent and lime reagents.
- Disassembling, cleaning, and storing transfer lines, pumps, and electrical lines.
- Shipping accumulated hazardous solids off-site to a permitted TSD facility.
- Removing office trailers, portable toilets, generators, forklift, and man lift.

Demobilization activities required for the semi-passive alkaline lagoon treatment system typically occur over a three week period and include:

- Disassembling, cleaning, and storing CUD capture lines, holding tanks, lift pumps, and transfer lines.
- Discharging treated water from the lagoon to Leviathan Creek.
- Draining treated ARD from the reaction tanks, lines, and bag filters into the lagoon.
- Draining lime from the feed pumps and lines.
- Disassembling, cleaning, and storing transfer lines, pumps, and electrical lines.
- Cleaning solids and scale from the interior of the reaction tanks and lime slurry tank.
- Shipping accumulated solids in the bag filters to an off-site non-hazardous waste landfill.
- Removing office trailers, portable toilets, generators, forklift, and man lift.

2.4.6 *Lessons Learned*

This section discusses the lessons learned during the technical evaluation of each treatment system. The discussion includes observations, recommendations, and ideas to be implemented during future operations and for similar treatment systems.

Lessons learned during the operation of active lime treatment system include:

- Lime feed pumps periodically plugged due to lime scaling. In addition, the lime slurry holding tank is not mixed, so precipitates tend to cake and form lumps that plug the outlet. The tank needs to be mixed to minimize lumping and cake formation, a higher purity lime needs to be used to improve pumpability, and a new pumping system needs to be designed that can handle high concentrations of lime without plugging.
- Phase II slurry lines from the Phase II clarifier to the pit clarifier continuously scale, restricting flow. Better lime control is necessary in the Phase II reaction tank to minimize excess calcium in the slurry passing through and scaling pipe surfaces.
- Aeration bars at the bottom of reaction tanks are undersized (too few holes and too small) and consistently plug. The aeration system needs to be redesigned to improve aeration mixing. A better method is needed to retrieve, maintain, and clean aeration bars. An alternative would be to use mechanical means of mixing instead of aeration.
- All process-monitoring probes continuously coat with scale and become ineffective within one to two weeks causing the lime dosing system to malfunction. Presently, pH samples are monitored externally and lime dosing is manually controlled. An alternate pH monitoring approach or different monitoring locations should be evaluated.
- Flocculent dosage is marginally effective for Phase I solids floc formation. A dosing study should be conducted or a different flocculent used to improve Phase I filter cake characteristics.

Lessons learned during the operation of the semi-passive alkaline lagoon treatment system include:

- The peristaltic pump used for lime delivery continually plugged due to viscous lime and lime scaling. A different lime delivery system needs to be designed and a higher purity used to improve pumpability.

- Existing variable frequency device and submersible pumps are under powered for the elevation head difference between CUD and the treatment facility. Larger pumps are needed to maintain efficient transfer of CUD water up to the treatment system.
- Bag filters may limit operations during freezing temperatures in fall and spring due to icing of the filter fabric, which will create backpressure within the system.
- The bag filters cannot be removed from the site until the end of the treatment season. Solids removal from the site requires dewatering the bag filters, cutting the bag filters open, and using a loader to scrape up material for placement in a roll off bin. A better method for handling of bag filters is needed.

2.5 Technology Evaluation Results

This section summarizes the evaluation of the metals data collected during the SITE demonstration with respect to meeting project objectives. Attainment of project primary objectives is described in Sections 2.5.1 and 2.5.2, while secondary objectives are provided by treatment system in Sections 2.5.3 and 2.5.4. Solids handling and disposal for each treatment system is discussed in Section 2.5.5.

Preliminary evaluation of the influent, effluent, and 4-day average effluent metals data included an assessment of data characteristics through quantitative and graphical analysis. Influent, effluent, and 4-day average effluent concentrations for the 10 metals of interest for each lime treatment system are presented in Tables B-1 through B-3 of Appendix B. Summary statistics calculated for these data sets include: mean, median, standard deviation, and coefficient of variation, which are presented in Tables B-4 through B-6 of Appendix B. Minimum and maximum concentrations are also presented.

Summary statistics for influent, effluent, and 4-day average effluent data were determined using Analyze-It Excel (Analyze-It 2004) and ProUCL (EPA 2004) statistical software. In addition, frequency, box-and-whisker, and probability plots were prepared to identify data characteristics and relationships, evaluate data fit to a distribution (for example, normal or lognormal), and to identify anomalous data points or outliers for the 10 target metals for each of the lime treatment systems. The results of statistical plotting showed no significant outliers in the influent, effluent, and 4-day average effluent data; therefore, no data were rejected from the data sets. The statistical plots also showed the metals influent and effluent concentrations to be normally distributed. Statistical plots are documented in the Technology Evaluation Report Data Summary (Tetra Tech 2004).

2.5.1 Primary Objective No.1: Evaluation of Metals Removal Efficiencies

The evaluation of the lime treatment systems focused on two primary objectives. The first objective was to determine the removal efficiencies for the primary metals of concern and the secondary water quality indicator metals. To successfully calculate removal efficiencies for each metal, influent concentrations must be significantly different than effluent concentrations. Based on preliminary statistical plots described in Section 2.5, the influent and effluent metals data sets were found to be normally distributed; therefore a paired Student's-t test (as described in EPA guidance [EPA 2000]) was used to determine if the influent and effluent concentrations were statistically different. For this statistical evaluation, if the P-value (test statistic) was less than the 0.05 significance level (or 95 percent confidence level), then the two data sets were considered statistically different. With a few exceptions, influent and effluent concentrations from each lime treatment system for the 10 metals were found to be statistically different (P-value was less than 0.05), and for these metals, removal efficiencies were calculated. Tables 2-2 through 2-4 present the average and range of removal efficiencies for filtered influent and effluent samples collected from each treatment system during the SITE demonstration and also the P-value for the paired Student's-t test analysis. The average influent and effluent metals concentrations for each treatment system are also presented. Where influent and effluent concentrations for a particular metal were not statistically different (P-value was greater than 0.05), removal efficiencies were not calculated for that metal, as indicated in the summary tables. In addition, where one or both concentrations for a metal were not detected in an individual influent/effluent data pair, those data points were not included in the determination of removal efficiencies.

For both modes of active lime treatment system operation, the average removal efficiency for the primary target metals was 99.6 percent over 20 sampling events, with the exception of lead at 74.6 to 78.3 percent removal. For the alkaline lagoon treatment system, the average removal efficiency for the primary target metals in the ARD was 99.2 percent over eight sampling events, with the exception of lead at 66.4 percent removal and copper at 58.3 percent removal. Removal efficiencies for lead during biphasic and monophasic treatment and copper during alkaline lagoon treatment were less than other metals because the influent concentrations of these two metals were already near or below the EPA discharge standards and the systems were not optimized for removal of these metals at such low concentrations. In the case of selenium during active biphasic treatment and selenium and cadmium during alkaline lagoon treatment, removal efficiencies were not calculated because the influent and effluent metals concentrations were not statistically different.

Table 2-2. 2002 and 2003 Removal Efficiencies for the Active Lime Treatment System - Biphasic Operation

Target Metal	Number of Sampling Events	Average Influent Concentration (µg/L)	Average Effluent Concentration (µg/L)	Paired Student's-t test P-value[1]	Average Removal Efficiency (%)	Range of Removal Efficiencies (%)
Primary Target Metals						
Aluminum	12/1	381,000	1,118	<0.05	99.7	99.2 to 99.9
Arsenic	12/1	2,239	8.6	<0.05	99.6	99.2 to 99.8
Copper	12/1	2,383	8.0	<0.05	99.7	99.4 to 99.8
Iron	12/1	461,615	44.9	<0.05	100	99.9 to 100
Nickel	12/1	7,024	34.2	<0.05	99 5	99.2 to 99.9
Secondary Water Quality Indicator Metals						
Cadmium	12/1	54.4	0.70	<0.05	98.7	97.5 to 99.4
Chromium	12/1	877	5.7	<0.05	99.3	93.8 to 99.9
Lead	12/1	7.6	2.0	<0.05	78.3	69.2 to 86.7
Selenium	12/1	4.3	3.8	0.65	NC	NC
Zinc	12/1	1,469	19.3	<0.05	98.7	97.4 to 99.4

[1] A P-value less than 0.05 indicates that influent and effluent data are statistically different
µg/L = Microgram per liter
% = Percent
NC = Not calculated as influent and effluent concentrations were not statistically different

Table 2-3. 2003 Removal Efficiencies for the Active Lime Treatment System - Monophasic Operation

Target Metal	Number of Sampling Events	Average Influent Concentration (µg/L)	Average Effluent Concentration (µg/L)	Paired Student's-t test P-value[1]	Average Removal Efficiency (%)	Range of Removal Efficiencies (%)
Primary Target Metals						
Aluminum	7	107,800	633	<0.05	99.5	99.0 to 99.8
Arsenic	7	3,236	6.3	<0.05	99.8	99.7 to 99.9
Copper	7	2,152	3.1	<0 05	99.4	99.0 to 99.7
Iron	7	456,429	176	<0.05	100.0	99.9 to 100.0
Nickel	7	2,560	46.8	<0.05	97.9	95.7 to 99.3
Secondary Water Quality Indicator Metals						
Cadmium	7	26.1	0.2	<0.05	99.1	98.4 to 99.7
Chromium	7	341	3.0	<0.05	99.0	95.6 to 99.8
Lead	7	6.2	1 6	<0.05	74.6	48.3 to 89.8
Selenium	7	16.6	2.1	<0.05	93.1	91.0 to 94.4
Zinc	7	538	5.6	<0.05	98.9	97.7 to 99.6

[1] A P-value less than 0.05 indicates that influent and effluent data are statistically different
µg/L = micrograms per liter
% = Percent

Table 2-4. 2002 Removal Efficiencies for the Semi-Passive Alkaline Lagoon Treatment System

Target Metal	Number of Sampling Events	Average Influent Concentration (µg/L)	Average Effluent Concentration (µg/L)	Paired Student's-t test P-value[1]	Average Removal Efficiency (%)	Range of Removal Efficiencies (%)
Primary Target Metals						
Aluminum	8	31,988	251	<0.05	99.2	98.0 to 99.5
Arsenic	8	519	5.8	<0.05	98 9	97.6 to 99.5
Copper	8	13.5	5.5	<0.05	58.3	27.7 to 74.5
Iron	8	391,250	148	<0.05	100	99.9 to 100
Nickel	8	1,631	22.6	<0.05	98.6	97.2 to 99.1
Secondary Water Quality Indicator Metals						
Cadmium	8	0.2988	0 4	0.12	NC	NC
Chromium	8	19.3	2.3	<0.05	88.5	83.1 to 92.3
Lead	8	5.1	1.7	<0.05	66.4	37.7 to 78.9
Selenium	8	3.3	3.2	0.92	NC	NC
Zinc	8	356	14.2	<0.05	96.0	90.6 to 98.2

[1] A P-value less than 0.05 indicates that influent and effluent data are statistically different
NC = Not calculated as influent and effluent concentrations were not statistically different
µg/L = micrograms per liter
% = Percent

Table 2-5. EPA Project Discharge Standards

Target Metals	Maximum (a) (µg/L)	Average (b) (µg/L)
Primary Target Metals		
Aluminum	4,000	2,000
Arsenic	340	150
Copper	26	16
Iron	2,000	1,000
Nickel	840	94
Secondary Water Quality Indicator Metals		
Cadmium	9.0	4.0
Chromium	970	310
Lead	136	5.0
Selenium	No Standard	5.0
Zinc	210	210

(a) Based on a daily composite of three grab samples
(b) Based on the average of four consecutive daily composite samples
µg/L = micrograms per liter

2.5.2 Primary Objective No.2: Comparison of Effluent Data to Discharge Standards

The second primary objective was to determine whether the concentrations of the primary metals of concern in the effluent from the lime treatment systems were below EPA discharge standards, as presented in Table 2-5. In addition, the attainment of discharge standards for the secondary water quality parameters was evaluated.

Although direct comparisons of the effluent data to the maximum and 4-day average discharge standards show that none of the concentrations exceeded the discharge standards, additional statistical tests were used to evaluate whether metals concentrations in the effluent streams were statistically different from the maximum daily discharge standards. Based on preliminary statistical plots described in Section 2.5, the metals effluent and 4-day average effluent concentrations were shown to be normally distributed; therefore, the one-sample parametric Student's-t test (as described in EPA guidance [EPA 2000]) was used in the comparison of the metals concentrations to the discharge standards. The one-sample parametric Student's-t test was used to determine if metals effluent and 4-day average effluent concentrations were significantly greater than the discharge standards (alternative or H_a hypothesis). The maximum daily discharge standards, maximum detected effluent concentrations, and average effluent concentrations are summarized in Table 2-6 and the 4-day average discharge standards and 4-day average effluent concentrations are summarized in Table 2-7. For the metals data sets that could be analyzed, the 1-tailed P-values (test statistic) for all of the tests were above the 0.05 significance level (or 95 percent confidence level) required for acceptance of the alternative hypothesis. Therefore, none of the effluent data for the lime treatment systems were considered significantly greater than the maximum daily discharge standards or the 4-day average discharge standards for any of the 10 target metals. There is no maximum daily discharge standard for selenium; therefore, there are no statistical results for selenium in Table 2-6.

In addition, cadmium was non-detect in all of the effluent samples collected from the monophasic lime treatment system; therefore, there are no statistical results for selenium in either Table 2-6 or 2-7 for the monophasic system.

Although the influent concentrations for the primary target metals were up to 3,000 fold above EPA discharge standards, both lime treatment systems were successful in reducing the concentrations of the primary target metals in the AMD and ARD to between 4 and 20 fold below the discharge standards.

Table 2-6. Results of the Student's-t Test Statistical Analysis for Maximum Daily Effluent Data

Analyte	Maximum Daily Discharge Limit (µg/L)	Maximum Detected Concentration in Effluent Stream (µg/L)	Average Concentration in Effluent Stream (µg/L)	1-Tailed P-value (Effluent Data > Maximum Daily Discharge Limit)	Effluent Concentration Significantly Greater than Maximum Daily Discharge Limit? (µg/L)
Alkaline Lagoon Student's-t test Comparisons					
Aluminum	4,000	639	251	1.0	No
Arsenic	340	13	5.8	1.0	No
Cadmium	9	0.70	0.38	1.0	No
Chromium	970	3.8	2.3	1.0	No
Copper	26	8.6	5.5	1.0	No
Iron	2,000	163	148	1.0	No
Lead	136	3.3	1.7	1.0	No
Nickel	840	47	23	1.0	No
Selenium	No Standard	6.3	3.2	Not Tested	Not Tested
Zinc	210	33	14	1.0	No
Biphasic Student's-t test Comparisons					
Aluminum	4,000	2,860	1,118	1.0	No
Arsenic	340	12	8.6	1.0	No
Cadmium	9	1.3	0.71	1.0	No
Chromium	970	46	5.7	1.0	No
Copper	26	13	8.1	1.0	No
Iron	2,000	243	45.9	1.0	No
Lead	136	4.4	2.0	1.0	No
Nickel	840	55	34.2	1.0	No
Selenium	No Standard	7.3	3.8	Not Tested	Not Tested
Zinc	210	38	19.3	1.0	No
Monophasic Student's-t test Comparisons					
Aluminum	4,000	1,090	633	1.0	No
Arsenic	340	11	6.3	1.0	No
Cadmium	9	ND	N/A	Not Tested	Not Tested
Chromium	970	12	3.0	1.0	No
Copper	26	5.4	3.1	1.0	No
Iron	2,000	350	176	1.0	No
Lead	136	4.5	1.6	1.0	No
Nickel	840	69	47	1.0	No
Selenium	No Standard	2.6	2.1	Not Tested	Not Tested
Zinc	210	12	5.6	1.0	No

µg/L = micrograms per liter
ND = Not detected (all results for cadmium in the effluent samples during monophasic operations were non-detect)
N/A = Not applicable

Table 2-7. Results of the Student's-t Test Statistical Analysis for 4-Day Average Effluent Data

Analyte	4-Day Average Discharge Limit (µg/L)	Maximum 4-Day Average Concentration in Effluent Stream (µg/L)	Average 4-Day Average Concentration in Effluent Stream (µg/L)	1-Tailed P-value (Effluent Data > Maximum Daily Discharge Limit)	Effluent Concentration Significantly Greater than Maximum Daily Discharge Limit? (µg/L)
Alkaline Lagoon Student's-t test Comparisons					
Aluminum	2,000	308	226	1 0	No
Arsenic	150	6.9	5.3	1.0	No
Cadmium	4	0 4	0.4	1.0	No
Chromium	310	2.6	2.2	1.0	No
Copper	16	6.3	5.3	1.0	No
Iron	1,000	203	140	1.0	No
Lead	5	2 1	1.7	1.0	No
Nickel	94	24.9	20.7	1.0	No
Selenium	5	3.7	3.1	0.9996	No
Zinc	210	18.4	12.4	1.0	No
Biphasic Student's-t test Comparisons					
Aluminum	2,000	1,820	971	0.9999	No
Arsenic	150	9.8	8.8	1.0	No
Cadmium	4	1.0	0 .77	1.0	No
Chromium	310	13.4	7.1	1.0	No
Copper	16	9.6	8.4	1.0	No
Iron	1,000	94.3	52.4	1.0	No
Lead	5	2.4	1.8	1.0	No
Nickel	94	498	35.5	1.0	No
Selenium	5	4.6	3.9	1.0	No
Zinc	210	27.5	20.0	1.0	No
Monophasic Student's-t test Comparisons					
Aluminum	2,000	765	579	0.9999	No
Arsenic	150	8.9	6.7	1.0	No
Cadmium	4	ND	N/A	Not Tested	No
Chromium	310	3.9	2.7	1.0	No
Copper	16	3.3	2 5	1.0	No
Iron	1,000	250	202	1 0	No
Lead	5	1.8	1.2	0.9998	No
Nickel	94	67.7	53.9	0.9928	No
Selenium	5	2.2	2.0	1.0	No
Zinc	210	6.5	5.0	1.0	No

µg/L = micrograms per liter
ND = Not detected (all results for cadmium in the effluent samples during monophasic operations were non-detect)
N/A = Not applicable

In addition, the concentrations of the secondary water quality indicator metals in the AMD and ARD were reduced to below the discharge standards. In both cases, statistical analysis showed that the effluent and 4-day average effluent concentrations did not exceed the discharge standards. Process water added during treatment accounted for less than one-half of one percent of total flow and did not provide treatment through dilution. These results demonstrate that the lime treatment systems are extremely effective at neutralizing acidity and reducing metals content in AMD and ARD to meet EPA discharge standards for the Leviathan Mine site.

2.5.3 Secondary Objectives for Evaluation of Active Lime Treatment System Unit Operations

The evaluation of the active lime treatment system at Leviathan Mine also included evaluation of four secondary objectives. These secondary objectives included:

- Documentation of operating parameters and assessment of critical operating conditions necessary to optimize system performance.

- Monitoring the general chemical characteristics of the AMD or ARD water as it passes through the treatment system.
- Evaluating operational performance and efficiency of solids separation systems.
- Documenting solids transfer, dewatering, and disposal operations.

Documentation of operating conditions, discussion of reaction chemistry, evaluation of metals removal by unit operation, and evaluation of solids separation are presented in the following sections. The data presented were compiled from observations during the demonstration as well as data summarized in the 2002 Year-End Report for Leviathan Mine (RWQCB 2003), 2003 Year-End Report for Leviathan Mine (RWQCB 2004), and the 2003 Early Response Action Completion Report for Leviathan Mine (ARCO 2004). Solids characterization and handling is documented in Section 2.5.5.

2.5.3.1 Operating Conditions

Operating conditions for the active lime treatment system in biphasic and monophasic modes are described below.

Biphasic Operations. Operation of the active lime treatment system in biphasic mode (Figure 1-2) involved pumping AMD out of the retention ponds to the head of the treatment system. Influent was pumped from Pond 1 and discharged into the Phase I reaction tank at an average flow rate of 638.7 L/min. Forty-five percent lime slurry was injected into the reaction tank at an average dose rate of 1,288 milliliter per minute (mL/min) to increase the pH to approximately 2.8 to 3.0. In this pH range, a portion of the dissolved ferrous iron is oxidized to ferric iron and precipitates out of solution (as ferric hydroxide) along with the majority of dissolved arsenic. Process water was drawn from upper Leviathan Creek to make up the lime slurry used in the treatment process. The AMD/lime slurry was sparged with compressed air at 2,400 L/min and mixed with a stirrer at 60 revolutions per minute (rpm) for approximately one hour. Following arsenic-rich iron precipitate formation, the AMD slurry was gravity drained into the Phase I flash/floc mixing tank where approximately 25 mL/min of Superfloc A-1849 RS (polymer) flocculent was added to promote aggregation of the arsenic-rich iron precipitate into a settleable floc. The AMD slurry was then discharged into the Phase I clarifier for floc settling and thickening. A floc settling rate of 23.1 mL/min was observed in a 1,000 milliliter (mL) Imhoff cone, well within the clarifier average HRT of 59 minutes. Approximately 19 L/min of solids were recycled from the Phase I clarifier to the Phase I reaction tank to provide seed for particle nucleation. Phase I of the treatment process occurred in an average HRT of 124.4 minutes. The thickened arsenic-rich iron solids were periodically pumped from the bottom of the Phase I clarifier into sludge holding tanks at an average rate of 11.3 L/min, and then into a batch filter press for dewatering. The thickened sludge was pressed twice per day for up to 8 hours, generating a total 1,320 kilogram (kg) of dry filter cake. Decant from the filter press was discharge to the Phase II reaction tank at an average rate of 11.6 L/min during pressing operations.

Supernatant from the Phase I clarifier was gravity drained into the Phase II reaction tank for additional lime treatment of remaining acidity and metals. Forty-five percent lime slurry was injected into the Phase II reaction tank at an average dose rate of 2,289 mL/min to increase the pH to approximately 7.9 to 8.2. The AMD/lime slurry was sparged with compressed air at 2,400 L/min and mixed with a stirrer at 60 rpm for approximately one hour. Following precipitate formation, the slurry was gravity drained into the Phase II flash/floc mixing tank where approximately 44 mL/min of polymer flocculent was added to promote aggregation of the precipitate into a settleable floc. The AMD slurry was then discharged into the Phase II clarifier for floc growth and partial thickening; however, floc was not settled in the clarifier. Instead, the slurry was pumped at an average flow rate of 638.7 L/min from the bottom of the Phase II clarifier to the pit clarifier for extended settling. A floc settling rate of 21.1 mL/min was observed in a 1,000 mL Imhoff cone, well within the clarifier average HRT of 59 minutes. Phase II of the treatment process occurred in an average HRT of 124.4 minutes. The pit clarifier provided an additional 79 hours (on average) of HRT for dissolution and reaction of any remaining lime with dissolved metals, oxidation and precipitation of residual ferrous iron, and precipitation of floc. Unsettled floc was captured on a silt screen near the discharge structure. An adjustable standpipe was used to control clarifier water elevation and HRT. On average, the pit clarifier captured 5,544 kg of dry solids per day at an average flow rate of 638.7 L/min. A summary of the system operational parameters is presented in Table 2-8.

Table 2-8. Biphasic Unit Operations Parameters

Parameter	Units	Range	Average
System Influent Flow Rate	(L/min)	586.7 to 662.4	638.7
Phase I Lime Dosage Rate	(mL/min)	1,183 to 1,335	1,288
Phase I Reaction Time	(min)	64.5 to 57.1	59.3
Phase I Aeration Rate	(L/min)	2,400	2,400
Phase I Flocculent Dosage Rate	(mL/min)	22.9 to 25.9	24.9
Phase I Solids Recycle Rate	(L/min)	18.9	18.9
Phase I Solids Settling Rate	(mL/min)	23.1	23.1
Phase I Residence Time	(min)	135.5 to 120	124.4
Filter Press Decant Rate	(L/min)	11.6	11.6
Filter Cake Generation Rate	(kg/day)	1,320.1	1,320.1
Phase II Lime Dosage Rate	(mL/min)	2,103 to 2,374	2,289
Phase II Reaction Time	(min)	64.5 to 57.1	59.3
Phase II Aeration Rate	(L/min)	2,400	2,400
Phase II Flocculent Dosage Rate	(mL/min)	40 to 45.2	43.6
Phase II Clarifier Solids Settling Rate	(mL/min)	21.1	21.1
Phase II Hydraulic Residence Time	(min)	135.5 to 120	124.4
Pit Clarifier Solids Accumulation Rate	(kg/day)	5,093 to 5750	5,544.2
Pit Clarifier Residence Time	(hr)	86 to 76.2	79
System Effluent Flow Rate	(L/min)	227.1 to 908.4	681.3

hr = hour; min = Minute
kg/day = Kilogram per day; mL/min = Milliliter per minute
L/min = Liter per minute

Monophasic Operations. The active lime treatment system operated in the monophasic mode (Figure 1-3) utilizes the same process equipment as the system operated in biphasic mode; however, the precipitation process results in a single output stream of metals-laden precipitate that is thickened in the Phase II clarifier and dewatered using the batch filter press. Other changes between operations include a lower influent flow rate of up to 246 L/min (due to HRT and thickening limitations of the Phase II clarifier), a lower lime dosage rate, and a difference in the makeup of the source water. Operation of the active lime treatment system in monophasic mode involved pumping low arsenic content ARD (50 percent from the CUD and 17.6 percent from Delta Seep) and high-arsenic content AMD (32.4 percent from Adit No.5) to the head of the treatment system. The blended influent was pumped to the Phase I reaction tank at an average flow rate of 222.6 L/min. Forty-five percent lime slurry was injected into the reaction tank at an average dose rate of 228.8 mL/min to increase the pH from 3.4 to 5.0. The purpose of this initial lime addition was to extend the period of lime dissolution and reaction with target metals. The slurry was sparged with compressed air at 2,400 L/min and mixed with a stirrer at 60 rpm for 170 minutes. The first phase of the monophasic treatment process occurred in an average HRT of 357 minutes.

The partially treated slurry was gravity drained from the Phase I clarifier into the Phase II reaction tank for additional lime treatment of remaining acidity and metals. Forty-five percent lime slurry was injected into the Phase II reaction tank at an average dose rate of 122.1 mL/min to increase the pH to approximately 7.3 to 7.5. The ARD/lime slurry was sparged with compressed air at 2,400 L/min and mixed with a stirrer at 60 rpm for 170 minutes. Following precipitate formation, the slurry was gravity drained into the Phase II flash/floc mixing tank where approximately 7 mL/min of polymer flocculent was added to promote aggregation of the precipitate into a settleable floc. The ARD slurry was then discharged into the Phase II clarifier for floc settling and thickening. A floc settling rate of 42.9 mL/min was observed in a 1,000 mL Imhoff cone, well within the clarifier average HRT of 170 minutes. The second phase of the monophasic treatment process occurred in an average HRT of 357 minutes. The thickened solids were periodically pumped from the bottom of the Phase II clarifier into sludge holding tanks at an average rate of 11.3 L/min, and then into a batch filter press for dewatering. The thickened sludge was pressed twice per day for up to 8 hours, generating a total 431 kg of dry filter cake. Decant from the filter press was discharge to the Phase II reaction tank at an average rate of 11.8 L/min during pressing operations. A summary of the system operational parameters is presented in Table 2-9.

2.5.3.2 Reaction Chemistry

The reaction chemistry for the active lime treatment system in biphasic and monophasic modes is described below.

Table 2-9. Monophasic Unit Operation Parameters

Parameter	Units	Range	Average
System Influent Flow Rate	(L/min)	210.5 to 246	222.6
Phase I Lime Dosage Rate	(mL/min)	216 to 253.2	228.8
Phase I Reaction Time	(min)	179 8 to 153.9	170
Phase I Aeration Rate	(L/min)	2,400	2,400
Phase I Hydraulic Residence Time	(min)	377.6 to 323.1	357.1
Phase II Lime Dosage Rate	(mL/min)	115.4 to 134.7	122.1
Phase II Reaction Time	(min)	179.8 to 153.9	170
Phase II Aeration Rate	(L/min)	2,400	2,400
Phase II Flocculent Dosage Rate	(mL/min)	6.4 to 7.4	6.7
Phase II Solids Settling Rate	(mL/min)	42.9	42.9
Phase II Hydraulic Residence Time	(min)	377.6 to 323.1	357.1
Filter Press Decant Rate	(L/min)	11.8	11.8
Filter Cake Generation Rate	(kg/day)	408 to 476	431
System Effluent Flow Rate	(L/min)	210.5 to 246	222.6

kg/day = Kilogram per day; min = Minute
L/min = Liter per minute; mL/min = Milliliter per minute

Biphasic Reaction Chemistry. Changes in AMD chemistry within the Phase I reaction tank are driven by the addition of lime and aeration of the AMD slurry. Lime addition consumes mineral acidity, raises solution pH, shifts the iron stability field toward ferric iron, and provides a source of hydroxide ion for ferric hydroxide formation. During precipitation, a large portion of the arsenic adsorbs to the ferric hydroxide precipitate. Aeration of the AMD slurry oxidizes ferrous iron to ferric iron and provides a source of dissolved oxygen for iron oxide formation, reducing the overall lime requirement. During Phase I of the biphasic process, reaction pH increased from 2.75 to 3.37 after lime addition, ferrous iron decreased from 8.2 to 7.8 mg/L, total iron decreased 15 percent from 558 to 500 mg/L, and arsenic decreased 94 percent from 2.93 to 0.171 mg/L. The data indicate that the majority of the iron is already in the ferric oxidation state, a small quantity of ferrous iron was oxidized to ferric iron, and arsenic co-precipitated with the ferric hydroxide. The data also indicate that mineral acidity was reduced as evidenced by an increase in pH and a decrease in solution ORP. Excess sulfate was removed from solution in the presence of excess calcium to form gypsum.

Additional changes in AMD slurry chemistry were observed in the Phase I clarifier, primarily due to the continued dissolution and reaction of lime with dissolved metals as well as settling of metal hydroxide and oxyhydroxide precipitates within the clarifier. Clarifier effluent pH increased from 3.37 to 3.73, ferrous iron decreased from 7.8 to 5.5 mg/L, total iron decreased 74 percent from 500 to 128 mg/L, and arsenic decreased another 29 percent from 0.171 to 0.121 mg/L. Field and analytical laboratory chemical parameters documenting Phase I reaction chemistry are provided in Table 2-10.

Changes in AMD chemistry within the Phase II reaction tank is also driven by the addition of lime and aeration of the AMD slurry. Reaction pH increased from 3.73 to 6.84 after excess

Table 2-10. Biphasic Phase I Unit Operation Reaction Chemistry

Parameter	Unit	Phase I Reactor			Phase I Clarifier		
		Influent	Effluent	Change	Influent	Effluent	Change
pH	(SU)	2.75	3.37	0.62	3.37	3 73	0.36
Oxidation Reduction Potential	(mV)	504	428	-76	428	396	-32
Total Iron (dissolved)	(mg/L)	553	83.7	-469.3	83.7	61.8	-21.9
Ferrous Iron	(mg/L)	8.2	7 8	-0.4	7.8	5.5	-2.3
Specific Conductance	(µmhos/cm)	4,407	4,045	-362	4,045	3,645	-400
Dissolved Oxygen	(mg/L)	4.3	4.5	0.2	4.5	4.4	-0.1
Temperature	(°C)	19.9	20.8	0.9	20.8	20.8	0
Sulfate	(mg/L)	4,830	4,040	-790	4,040	4,130	90
Total Alkalinity	(mg/L)	< 0.002	<2	NC	<2	<2	NC
Total Dissolved Solids	(mg/L)	8,710	6,360	-2,350	6,360	6,490	130

µmhos/cm = Micromhos per centimeter; mV = Millivolt; NC = Not calculated
°C = Degree Celsius; mg/L = Milligram per liter; SU = Standard unit

lime addition, ferrous iron decreased 71 percent from 5.5 to 1.6 mg/L, total iron decreased 99 percent from 61.8 to 0.285 mg/L, and arsenic decreased 92 percent from 0.121 to 0.089 mg/L. The data indicate that the majority of the iron was converted to the ferric oxidation state, arsenic continued to co-precipitate with the ferric hydroxide, and that 54 to 99 percent of all other metals were precipitated from solution as metal hydroxides and oxyhydroxides. The remaining mineral acidity was completely consumed by excess lime in solution, yielding a bicarbonate alkalinity of 7 mg/L. Excess sulfate continued to be removed from solution in the presence of excess calcium to form gypsum.

Additional changes in AMD slurry chemistry were observed in the pit clarifier, primarily due to the continued dissolution and reaction of lime with dissolved metals as well as settling of metal hydroxide and oxyhydroxide precipitates within the pit clarifier. The extended HRT in the pit clarifier allowed between 16 and 80 percent removal of dissolved metals after initial settling. Total and ferrous iron was no longer detected in solution. Clarifier effluent pH increased from 6.84 to 8.07 within the Phase II plate clarifier (pass through only) then decreased to 7.64 in the discharge from the pit clarifier. Bicarbonate alkalinity initially increased to 19.8 mg/L within the Phase II plate clarifier, before decreasing to 12.8 mg/L in the pit clarifier effluent. Approximately 30 percent of the combined hydrated lime dose 4.45 gram per liter (g/L) was used to neutralize acidity, while the remainder of the dissolved lime was used for formation of metal hydroxide precipitates and alkalinity. A small portion of the lime never dissolves, remaining as inert solid. Field and analytical laboratory chemical parameters documenting Phase I reaction chemistry are provided in Table 2-11.

Monophasic Reaction Chemistry. Monophasic operation of the active lime treatment system differs from biphasic operation in that arsenic is not being selectively removed from solution prior to precipitation of all other metals. In addition, the Phase I reaction tank is used during Monophasic operations, but only to increase the time available for dissolution of lime. Finally, the source water treated was a blend of ARD and AMD. During Phase I of the monophasic process, reaction pH increased from 3.44 to 5.1 after addition of a large dose of lime, ferrous iron decreased from 8.2 to 6.4 mg/L, total iron decreased 58.5 percent from 485 to 201 mg/L, and 38 to 99 percent of all other metals (primarily aluminum, arsenic, copper, chromium) were precipitated from solution as metal hydroxides and oxyhydroxides. The data indicate that the majority of the iron is already in the ferric oxidation state, a small quantity of ferrous iron was oxidized to ferric iron, and mineral acidity was reduced as evidenced by an increase in pH and a decrease in solution ORP. Excess sulfate was removed from solution in the presence of excess calcium to form gypsum.

Changes in chemistry within the Phase II reaction tank was driven by the addition of a second small dose of lime to the ARD/AMD slurry. Reaction pH increased from 5.04 to 7.28 after excess lime addition, ferrous iron was completely oxidized to ferric iron, total iron decreased 99 percent from 201 to 2.16 mg/L, and 77 to 99 percent of all remaining metals were precipitated from solution as metal hydroxides and oxyhydroxides. The remaining mineral acidity was completely consumed by excess lime in solution, yielding a bicarbonate alkalinity of 47.6 mg/L. Excess sulfate was not substantially reduced, likely due to the limited amount of calcium available for super saturation of the solution with respect to gypsum.

Additional changes in ARD/AMD slurry chemistry were observed in the Phase II clarifier, primarily due to the continued dissolution and reaction of lime with dissolved metals as well as settling of metal hydroxide and oxyhydroxide precipitates within the clarifier. Clarifier influent pH changed substantially after the ARD/AMD slurry was discharged from the Phase II reactor, increasing from 7.28 to 8.01. Sulfate dropped 80 mg/L prior to entering the clarifier, and another 150 mg/L prior to discharge. Both of these observations demonstrate that additional lime dissolution

Table 2-11. Biphasic Phase II Unit Operation Reaction Chemistry

Parameter	Unit	Phase II Reactor			Pit Clarifier		
		Influent	Effluent	Change	Influent	Effluent	Change
pH	(SU)	3.73	6.84	3.11	8.07	7.64	-0.43
Oxidation Reduction Potential	(mV)	396	227	-169	142	143	1
Total Iron (dissolved)	(mg/L)	61.8	0.285	-61.5	0.096	< 0.038	-0.058
Ferrous Iron	(mg/L)	5.5	1 6	-3.9	< 0.1	<0.1	0
Specific Conductance	(µmhos/cm)	3,645	3,765	120	3,500	3,400	-100
Dissolved Oxygen	(mg/L)	4.4	3 1	-1.3	3.3	3.6	0.3
Temperature	(°C)	20.8	20.5	-0.3	20.9	21	0.1
Sulfate	(mg/L)	4,130	2,890	-1,240	2,610	2,520	-90
Total Alkalinity	(mg/L)	<2	7	7	19.8	12.8	-7
Total Dissolved Solids	(mg/L)	6,490	3,960	-2,530	3,800	3,670	-130

µmhos/cm = Micromhos per centimeter; mV = Millivolt; SU = Standard unit
°C = Degree Celsius; mg/L = Milligram per liter

occurred and that gypsum formed with the dissolution of calcium into solution. Approximately 67 percent of the combined hydrated lime dose 1.29 g/L was used to neutralize acidity, while the remainder of the dissolved lime was used for formation of metal hydroxide precipitates and alkalinity. A small portion of the lime never dissolves, remaining as inert solid. Field and analytical laboratory chemical parameters documenting monophasic reaction chemistry are provided in Table 2-12.

2.5.3.3 Metals Removal by Unit Operation

Metals removal by each unit operation of the active lime treatment system is described below for both the biphasic and monophasic modes of operation.

Biphasic Operations. Aluminum, arsenic, cadmium, chromium, copper, iron, nickel, and zinc are the metals of concern in the AMD from the retention ponds. All of the dissolved metals of concern exceeded their discharge standards after lime addition, mixing, and air sparging in the Phase I reaction tank. Phase I reaction tank metals removal efficiencies ranged from -1.41 to 94.16 percent, with the majority of the mass removal associated with arsenic, chromium, and iron. All of the dissolved metals of concern exceeded their discharge standards after settling in the Phase I clarifier, with the exception of arsenic, which appears to have continued co-precipitation with iron.

Following lime addition, mixing, and air sparging in the Phase II reaction tank, only dissolved lead and nickel exceeded their respective discharge standards. Phase II reaction tank removal efficiencies ranged from 54 to 99.74 percent, with the majority of the mass removal associated with aluminum, copper, iron, nickel, and zinc. Almost all of the metals of concern met discharge standards in the pit clarifier after an extended residence time for lime dissolution, reaction, and precipitate settling. Aluminum exceeded the 4 day moving average discharge standard, but not the daily maximum standard due to a pH excursion above 7.5. Aluminum typically reenters solution in a basic solution with low solution ionic strength. Treatment system removal efficiencies for the metals of concern ranged from 99.26 percent for zinc to 99.99 percent for iron. A summary of unit operations concentration and removal efficiency data for the metals of concern is presented in Table 2-13 for both Phase I and Phase II unit operations.

An evaluation of metals and sulfate load reduction was prepared for biphasic operations based on unit operations data collected on August 12, 2003. A total metals load of 1,287 kg and a sulfate load of 4,541 kg entered the active lime treatment system. A total of 524 kg of metals and 743 kg of sulfate were precipitated out of solution, following the addition of 1,507 kg of hydrated lime to the AMD in the Phase I reaction tank, leaving 1,207 kg of metals and 3,798 kg of sulfate in solution. The Phase I clarifier separated 498 kg of metals and 658 kg of sulfate from solution, allowing 1,234 kg of metals (1,131 kg in solution) to discharge to the Phase II reaction tank. A total of 1,527 kg of metal precipitate, gypsum, and undissolved hydrated lime (Phase I clarifier settled solids) was discharged to the filter press for dewatering, generating a filter cake containing 518.7 kg of metals and a filter press decant containing 10.8 kg of metals. The filter press decant was discharged to the Phase II reaction tank for additional metals removal.

An additional 540 kg of metals and 1,166 kg of sulfate were precipitated out of solution, following addition of 2,680 kg of hydrated lime to the AMD slurry in the Phase II reaction tank, leaving 1,532 kg of metals and 2,717 kg of sulfate in solution. The Phase II clarifier was not used to separate metals from solution, instead serving as a retention tank for additional metals precipitate formation. A total of 7,188 kg of soluble metals, metal precipitate, gypsum, and undissolved hydrated

Table 2-12. Monophasic Unit Operation Reaction Chemistry

Parameter	Unit	Phase I Reactor			Phase II Reactor			Phase II Clarifier		
		Influent	Effluent	Change	Influent	Effluent	Change	Influent	Effluent	Change
pH	(SU)	3.44	5.1	1.66	5.04	7.28	2.24	8.01	7.91	-0.1
Redox Potential	(mV)	349	101	-248	147	33	-114	6	5	-1
Total Iron	(mg/L)	485	201	-284	201	2.16	-198.8	0.232	0.221	-0.011
Ferrous Iron	(mg/L)	8.2	6.4	-1.8	3.2	< 0.1	-3.2	< 0.1	< 0.1	0
Specific Conductance	(µmhos/cm)	2577	2370	-207	2210	2320	110	2155	2247	92
Dissolved Oxygen	(mg/L)	4.5	3.9	-0.6	4.7	4.5	-0.2	4.2	4.4	0.2
Temperature	(°C)	16	16.4	0.4	17.4	17.7	0.3	18.2	15.9	-2.3
Sulfate	(mg/L)	2510	2030	-480	2020	2070	50	1990	1840	-150
Total Alkalinity	(mg/L)	< 2	< 2	0	<2	47.6	46.6	47.6	43	-4.6
Total Dissolved Solids	(mg/L)	4370	3450	-920	3440	3400	-40	3170	3190	20

µmhos/cm = Micromhos per centimeter; mV = Millivolt; SU = Standard unit
°C = Degree Celsius; mg/L = Milligram per liter

Table 2-13. Biphasic Unit Operation Metals Removal Efficiencies

Parameter	Phase I Reactor			Phase I Clarifier		Phase II Reactor		Pit Clarifier		
	Influent (µg/L)	Effluent (µg/L)	Removal Efficiency (%)	Effluent (µg/L)	Removal Efficiency (%)	Effluent (µg/L)	Removal Efficiency (%)	Influent (µg/L)	Effluent (µg/L)	Removal Efficiency (%)
Aluminum	371,000	347,000	6.47	335,000	3.46	878	99.74	2,950	2,200	25.42
Arsenic	2,930	171	94.16	121	29.24	8.9	92.64	6.1	<7.7	36.89
Cadmium	55.6	51.2	7.91	52.3	-2.15	2.8	94.65	0.57	0.35	38.60
Chromium	1,000	529	47.10	549	-3.78	4	99.27	5	3.9	22.00
Copper	2,210	2,090	5.43	2,080	0.48	7.8	99.63	7.5	<5.8	61.33
Iron	553,000	83,700	84.86	61,800	26.16	285	99.54	96.3	<38.4	80.06
Lead	1.7	5.3	-211.76	15.0	-183.02	6.9	54.00	6.1	4.4	27.87
Nickel	6,490	6,230	4.01	6,480	-4.01	399	93.84	45.9	25	45.53
Selenium	<2.6	4.8	-72.92	<13	-26.15	<2.6	80.00	<2.6	<2.6	0.00
Zinc	1,420	1,440	-1.41	1,490	-3.47	15.2	98.98	12.5	10.4	16.80

% = Percent; µg/L = Microgram per liter

lime was pumped out of the bottom of the Phase II clarifier up hill to the pit clarifier for final settling, generating 5,642 kg of clarifier solids. A total of 1,318 kg of metals (primarily calcium), 2,369 kg of sulfate, and 228 kg of suspended solids were discharge from the pit clarifier to Leviathan Creek. A total of 4,187 kg of hydrated lime was required to neutralize 2,464 kg acidity (as hydrated lime) and precipitate 906 kg of metals (excluding added calcium) and 2,172 kg of sulfate from the AMD on August 12, 2003.

Monophasic Operations. Aluminum, arsenic, cadmium, chromium, copper, iron, nickel, selenium, and zinc are the metals of concern in the combined AMD and ARD from the adit, PUD, CUD, and Delta Seep. All of the dissolved metals of concern, with the exception of chromium, exceeded their discharge standards after lime addition, mixing, and air sparging in the Phase I reaction tank. Phase I reaction tank removal efficiencies ranged from 38.77 to 99.42 percent, with the majority of the mass removal associated with aluminum, arsenic, chromium, copper, and iron. However, metals were not settled out of solution in the Phase I clarifier; instead the slurry was discharged to the Phase II reaction tank. Following lime addition, mixing, and air sparging in the Phase II reaction tank; only dissolved iron exceeded its discharge standard. Phase II reaction tank removal efficiencies ranged from 77.06 to 99.47 percent, with the majority of the mass removal associated with aluminum, arsenic, nickel, and iron. Arsenic appears to have co-precipitated with iron in both the Phase I and Phase II reaction tanks. Additional aluminum and iron precipitation occurred in the flash/floc tank between the Phase II reaction tank and the Phase II clarifier. All of the metals of concern met discharge standards in the Phase II clarifier effluent. Treatment system removal efficiencies for the metals of concern ranged from 80.43 percent for lead to 99.95 percent for iron. A summary of unit operations concentration and removal efficiency data for the metals of concern is presented in Table 2-14.

An evaluation of metals and sulfate load reduction was prepared for monophasic operations based on unit operations data collected on July 3, 2003. A total metals load of 294.3 kg and a sulfate load of 779.8 kg entered the active lime treatment system. A total of 119 kg of metals and 149 kg of sulfate were precipitated out of solution, following the addition of 260.7 kg of hydrated lime to the combined ARD and AMD in the Phase I reaction tank, leaving 293.3 kg of metals and 630.7 kg of sulfate in solution. The slurry passed

Table 2-14. Monophasic Unit Operation Removal Metals Efficiencies

Parameter	Phase I Reactor			Phase II Reactor			Phase II Clarifier		
	Influent (µg/L)	Effluent (µg/L)	Removal Efficiency (%)	Influent (µg/L)	Effluent (µg/L)	Removal Efficiency (%)	Influent (µg/L)	Effluent (µg/L)	Removal Efficiency (%)
Aluminum	119,000	4,360	96.34	4,360	1,000	77.06	509	584	-14.73
Arsenic	3,470	709	79.57	709	17.6	97.52	5.7	<9.7	14 91
Cadmium	45.7	15	67.18	15	<0 16	99.47	<0.16	<0.16	0.00
Chromium	327	1.9	99.42	1.9	3.2	-68.42	0.79	<0.67	57.59
Copper	549	52.7	90.40	52.7	4.7	91.08	2	<1.9	52.50
Iron	485,000	201,000	58.56	201,000	2,160	98.93	232	221	4.74
Lead	2.3	3.8	-65.22	3.8	<0.9	96.54	<0.9	<0.9	0.00
Nickel	2,760	1,690	38.77	1,690	68.2	95.96	47.8	41.8	12.55
Selenium	29.4	13	55.78	13	<1.8	93.08	<1.8	<1.8	0.00
Zinc	583	342	41.34	342	12 7	96.29	7.8	2.6	66.67

% = Percent µg/L = Microgram per liter

through the Phase I clarifier with minimal precipitate settling and discharged into the Phase II reaction tank. An additional 159.6 kg of metals was precipitated out of solution, following addition of 139.3 kg of hydrated lime to the ARD/AMD slurry in the Phase II reaction tank, leaving 261.7 kg of metals and 643.1 kg of sulfate in solution. The sulfate load increased by a total of 15 kg within the Phase II reaction tank. The Phase II clarifier separated 141.6 kg of metals and 71.5 kg of sulfate from solution, allowing 279.7 kg of metals (primarily calcium) and 571.6 kg of sulfate to discharge to Leviathan Creek. A total of 439.5 kg of metal precipitate, gypsum, and undissolved hydrated lime (Phase II clarifier settled solids) was discharged to the filter press for dewatering, generating a filter cake containing 216.1 kg of metals and a filter press decant containing 5.7 kg of metals. The filter press decant was discharged to the Phase II reaction tank for additional metals removal. A total of 400 kg of hydrated lime was required to neutralize 300 kg acidity (as hydrated lime) and precipitate 190.9 kg of metals (excluding added calcium) and 208.2 kg of sulfate from the AMD on July 3, 2003.

2.5.3.4 Solids Separation

Metals and solids removal by solids separation techniques used during the operation of the active lime treatment system is described below for both the biphasic and monophasic modes of operation.

Biphasic Operations. Precipitate generated during operation of the active lime treatment system in biphasic mode is separated from AMD using plate clarifiers, a filter press, and a pit clarifier with extended hydraulic residence time. Phase I of the treatment process is optimized for precipitation of arsenic and iron from solution; therefore, Phase I solids separation techniques are focused on minimizing the mass of arsenic-rich hazardous waste requiring disposal. Over 67 percent of arsenic in solution was removed in the Phase I plate clarifier and over 99 percent of the arsenic was removed from the settled solids. Chromium, iron, and selenium were also precipitated from solution during Phase I of the treatment process. The Phase I plate clarifier removed over 99 percent of suspended solids from solution. Additional suspended solids removal could be achieved by adding more polymer during the flocculation process. The filter press concentrated arsenic, chromium, iron, selenium, and settled solids by 80 to 99 percent. Metals and solids removal efficiencies for Phase I solids separation equipment are provided in Table 2-15.

The Phase I clarifier operated with a HRT of 59 minutes, well within a solids settling time of 43 minutes. Metals and solids were concentrated between 120 and 3,250 percent in the Phase I clarifier. The clarifier operated with a 45 to 60 centimeter thick sludge blanket with periodic transfer of settled solids (11.3 L/min for up to 7 minutes per hour [min/hr]) to the sludge holding tanks for dewatering with a filter press. Seed floc was provided to the Phase I reaction tank through the transfer of settled solids from the clarifier at 19 L/min. .The filter press required approximately 8 hours per pressing with two pressings per day at a feed rate of 19 L/min, initially generating 11.6 L/min of decant that was discharged to the Phase II reaction tank. The time required for filter pressing could be reduced through generation of larger particle sizes during the flocculation and clarification process. The filter press generated 1,320 kg of cake per day with a moisture content ranging from 54 to 63 percent. Filter cake was dropped from the filter press into a roll-off bin for off-site disposal as a hazardous waste.

Phase II of the treatment process is optimized for precipitation of the remaining metals from solution, generating a non-hazardous solid waste stream. The Phase II plate clarifier was not operated for solids thickening, serving as a tank for particle growth prior to extended settling in the pit clarifier. Particle growth in the plate clarifier provided an additional 13 to 44 percent removal of dissolved metals (primarily aluminum and iron) from solution. Extended settling in the pit clarifier promoted removal of 96 to 99 percent of metals and suspended solids from solution. Effluent from the pit clarifier met EPA discharge criteria. Additional suspended solids

Table 2-15. Biphasic Phase I and Phase II Solids Separation Efficiencies

Parameter	Phase I Clarifier			Filter Press			Phase II Clarifier			Pit Clarifier	
	Unfiltered Influent (µg/L)	Unfiltered Effluent (µg/L)	Percent Removal (%)	Unfiltered Solids (µg/L)	Unfiltered Effluent (µg/L)	Percent Removal (%)	Unfiltered Influent (µg/L)	Unfiltered Effluent (µg/L)	Percent Removal (%)	Unfiltered Effluent (µg/L)	Percent Removal (%)
Aluminum	361,000	339,000	6.09	543,000	61,100	88 75	305,000	239,000	21.64	2,690	98.87
Arsenic	2,110	688	67.39	19,000	35.3	99.81	698	412	40.97	< 10.3	97.50
Cadmium	53.2	50.4	5.26	64.5	31 0	51.94	45.8	37.2	18.78	< 0.39	98.95
Chromium	973	499	48.72	4,430	16.6	99 63	461	344	25 38	4.0	98.84
Copper	2,200	2,060	6.36	2,740	375.00	86.31	1,740	1,360	21.84	6.6	99 51
Iron	500,000	128,000	74.40	3,030,000	8,980.00	99.70	124,000	79,000	36.29	289	99.63
Lead	6.5	7.0	-7.69	42.3	5.8	86.29	12.7	7.1	44.09	6.0	15 49
Nickel	6,430	6,110	4.98	5,540	3,650	34.12	5,530	4,780	13 56	32.6	99 32
Selenium	5.5	3.0	45 45	< 13	<2.6	80 00	< 2 6	< 2.6	0.00	<2.6	0.00
Zinc	1,450	1,420	2.07	1,220	766	37 21	1,300	976	24.92	8.4	99.14
TSS	3,660,000	268,000	99.99	119,000,000	67,000	99.94	6,990,000	6,140,000	12.16	243,000	96.04

% = Percent µg/L = Microgram per liter

removal could be achieved by adding more polymer during the flocculation process. Metals and solids removal efficiencies for Phase II solids separation equipment are provided in Table 2-15.

The Phase II plate clarifier operated with a HRT of 59 minutes, well within a solids settling time of 47 minutes. However, the plate clarifier is unable to handle the solids load generated at the system treatment rate. Therefore the solids slurry was pumped out of the bottom of the plate clarifier and up hill for extended settling in the 3.1 million liter pit clarifier. The pit clarifier provided an average of 79 hours of HRT for dissolution and reaction of any remaining lime with metals and solids settling. Approximately 1 million liters of solids slurry were discharged to the pit clarifier each day, generating 5,544 kg of solids. On average 23 centimeters of air dried sludge is deposited in the pit clarifier during a treatment season. Air dried, non-hazardous sludge is removed from the pit clarifier every three years and disposed of on site. Approximately six weeks was required to reduce the water content of the sludge from 97.5 to 80.3 percent moisture.

Monophasic Operations. Precipitate generated during operation of the active lime treatment system in monophasic mode is separated from AMD using a plate clarifier and a filter press. Phase I process equipment was used to provide an initial bump in the pH of the combined ARD/AMD. The Phase I plate clarifier was not operated for solids thickening, serving as a tank for particle growth prior to discharge to the Phase II reaction tank. The Phase II plate clarifier removed between 83 and 99 percent of the metals and 99 percent of suspended solids from solution prior to supernatant discharge to Leviathan Creek. The filter press concentrated metals and settled solids by 99 percent. Metals and solids removal efficiencies for Phase II solids separation equipment are provided in Table 2-16.

The Phase II clarifier operated with a HRT of 170 minutes, well within a solids settling time of 23.3 minutes. Metals and solids were concentrated between 720 and 2,770 in the Phase II clarifier. The clarifier operated with a 60 to 75 centimeter thick sludge blanket with periodic transfer of settled solids (11.3 L/min for up to 7 min/hr) to the sludge holding tanks for dewatering with a filter press. The filter press required approximately 8 hours per pressing with two pressings per day at a feed rate of 19 L/min, initially generating 11.6 L/min of decant that was discharged to the Phase II reaction tank. The time required for filter pressing could be reduced through generation of larger particle sizes during the flocculation and clarification process. The filter press generated 431 kg of cake per day with a moisture content of 76 percent. Filter cake was dropped from the filter press into a roll-off bin for off-site disposal as a hazardous waste.

2.5.4 Secondary Objectives for Evaluation of Semi-Passive Alkaline Lagoon Treatment System Unit Operations

The evaluation of the semi-passive alkaline lagoon treatment system at Leviathan Mine also included evaluation of four secondary objectives (see Section 2.5.3). Documentation of operating conditions, discussion of reaction chemistry, evaluation of metals removal by unit operation, and evaluation of solids separation are presented in the following sections. The data presented were compiled from observations during the demonstration as well as data summarized in the 2002 Early Response Action Completion Report for Leviathan Mine (ARCO 2003). Solids characterization and handling is documented in Section 2.5.5.

2.5.4.1 Operating Conditions

Operation of the alkaline lagoon treatment system (Figure 1-4) involved pumping ARD from the CUD to the head of the treatment system, adjacent to the settling lagoon. ARD was

Table 2-16. Monophasic Solids Separation Efficiencies

Parameter	Phase II Clarifier			Filter Press		
	Unfiltered Influent (µg/L)	Unfiltered Effluent (µg/L)	Percent Removal (%)	Unfiltered Clarifier (µg/L)	Unfiltered Effluent (µg/L)	Percent Removal (%)
Aluminum	77,900	910	98.83	632,000	245	99.96
Arsenic	1,850	<15.9	99.57	16,100	9.1	99.94
Cadmium	24.6	<0.16	99.67	220	<0.16	99.96
Chromium	213	<1.7	99.60	1,800	7.6	99.58
Copper	330	<2.5	99.62	2,750	<1.9	99.97
Iron	267,000	1,360	99.49	2,500,000	226	99.99
Lead	2.7	<0.9	83.33	74.8	<0.9	99.39
Nickel	1,860	50.2	97.30	13,400	60.8	99.55
Selenium	16	<1.8	94.38	<1.8	<1.8	0.00
Zinc	386	5.8	98.50	3,100	<1.3	99.98
TSS	1,490,000	<10,000	99.66	12,400,000	<10,000	99.96

% = Percent µg/L = Microgram per liter

pumped uphill from the CUD at an average flow rate of 78.7 L/min into the first lime contact reactor. Forty-five percent lime slurry was injected into the reaction tank at an average dosage rate of 52.4 mL/min to increase the pH of the ARD to approximately 8.0. Process water was drawn from upper Leviathan Creek to make up the lime slurry used in the treatment process. The lime slurry was mixed with the ARD by sparging compressed air into the tank at 378 L/min. The partially treated ARD was then gravity drained into a second reaction tank where additional lime (52.4 mL/min) was injected in the slurry and sparged with air. The process was repeated in a third reaction tank. Sequential addition of lime in three reaction tanks was used to ensure lime dissolution and maximize oxidation of ferrous iron to ferric iron, which reduces lime demand. Following metal precipitate formation, the ARD slurry was gravity drained to five bag filters for separation of metal precipitate from solution. On average, the five bag filters captured a total of 88.9 kg of dry solids per day. ARD slurry passing through the five bag filters was discharge to the settling lagoon at a combined average flow rate of 78.7 L/min. The active portion of the treatment process occurred in an average HRT of 144 minutes. The passive settling lagoon provided an average of 16.7 days HRT (using an operational volume of 1,892,500 liters) for dissolution and reaction of any remaining lime with dissolved metals, oxidation and precipitation of residual ferrous iron, and precipitation of solids passing through the bag filters. Unsettled solids are captured on two silt screens within the lagoon. On average, the settling lagoon captured 29.2 kg of dry solids per day at an average flow rate of 78.7 L/min. A summary of the system operational parameters is presented in Table 2-17.

2.5.4.2 Reaction Chemistry

Operation of the semi-passive alkaline lagoon treatment system is similar to monophasic operation of the active lime treatment system, in that selective precipitation of a single metal prior to precipitation of all other metals is not necessary. Lime addition occurs in three consecutive steps to provide adequate time for lime dissolution and contact with dissolved metals in the ARD. Aeration is used for both mixing of the ARD slurry as well as to promote oxidation of ferrous to ferric iron, thereby decreasing lime demand. Following lime addition and aeration mixing, reaction pH increased from 4.59 to 8.02 after sequential addition of lime to the three reaction tanks, ferrous iron decreased 89 percent from 6.75 to 0.7 mg/L, total iron decreased 99 percent from 394 to 1.5 mg/L, and 65 to 99 percent of all other metals (primarily aluminum, arsenic, nickel, and zinc) were precipitated from solution as metal hydroxides and oxyhydroxides. The data indicate that the majority of the iron is already in the ferric oxidation state, a small quantity of ferrous iron was oxidized to ferric iron, and mineral acidity was reduced as evidenced by an increase in pH. The remaining mineral acidity was completely consumed by excess lime in solution, yielding a bicarbonate alkalinity of 69.1 mg/L. Excess sulfate was not reduced, likely due to the limited amount of calcium available for super saturation of the solution with respect to gypsum. Slight changes in ARD chemistry were observed in the effluent from the bag filters, primarily associated with a slight increase in total iron and specific conductance and a slight decrease in ferrous iron.

Table 2-17. Alkaline Lagoon Unit Operation Parameters

Parameter	Units	Range	Average
System Influent Flow Rate	(L/min)	61.7 to 111	78.7
Reactor Lime Dosage Rate (per reactor)	(mL/min)	41 to 71	52.4
Reaction Time (each reactor)	(min)	34.1 to 61.4	48.1
Aeration Rate (each reactor)	(L/min)	378	378
Bag Filtration Rate (per bag)	(L/min)	12.4 to 22.2	15.75
Bag Filter Solids Accumulation Rate	(kg/day)	69 7 to 125.4	88.9
System Hydraulic Residence Time	(min)	102.3 to 184.2	144.3
Lagoon Hydraulic Residence Time	(day)	12 to 21.3	16.7
Lagoon Solids Accumulation Rate	(kg/day)	22.9 to 41.2	29.2
System Batch Discharge Rate	(L/min)	311 to 424	359

kg/day = Kilogram per day min = Minute
L/min = Liter per minute mL/min = Milliliter per minute

Continued lime dissolution likely oxidized the remaining ferrous iron to ferric iron. Increases in total iron as well as other metals were likely related to fine particulates passing through the bag filters.

Additional changes in ARD chemistry were observed in the settling lagoon, primarily due to the continued dissolution and reaction of lime with dissolved metals as well as settling of metal hydroxide and oxyhydroxide precipitates. The extended HRT in the settling lagoon allowed between 60 and 97 percent removal of dissolved metals from bag filter discharge. Ferrous iron was no longer detected in solution; however, lagoon pH remained constant and sulfate actually increased slightly, indicating completion lime dissolution (limited excess calcium). Approximately 36 percent of the combined hydrated lime dose 1.63 g/L added to the three reaction tanks was used to neutralize acidity, while the remainder of the dissolved lime was used for formation of metal hydroxide precipitates and alkalinity. Field and analytical laboratory chemical parameters documenting alkaline lagoon reaction chemistry are provided in Table 2-18.

2.5.4.3 Metals Removal by Unit Operation

Aluminum, arsenic, iron, lead, nickel, and zinc are the metals of concern in the ARD from the CUD. Only dissolved iron exceed the discharge standards after sequential lime addition and air sparging in the reaction tanks. Reaction tank removal efficiencies ranged from 88.24 to 99.62 percent. The majority of iron and the other metals of concern were accumulated in the bag filters. However, aluminum, iron, and nickel reentered solution in the bag filter effluent at concentrations exceeding discharge standards. The increase in the dissolved concentrations of these three metals is likely due to fine particulates passing through the bag filters. All of the metals of concern met discharge standards in the lagoon after an extended time for additional lime dissolution, reaction, and precipitate settling. Treatment system removal efficiencies for the metals of concern ranged from 88.24 percent for lead to 99.88 percent for iron. A summary of unit operations concentration and removal efficiency data for the metals of concern is presented in Table 2-19.

An evaluation of metals load reduction was prepared based on unit operations data collected on July 30, 2002. A total metals load of 100.3 kg and a sulfate load of 216.4 kg entered the treatment system. A total of 57.2 kg of metals was precipitated out of solution, following the sequential addition of 185.8 kg of hydrated lime to the ARD in the three reaction tanks, leaving 90.7 kg of metals in solution. The slurry was discharged from the third reaction tank and into five bag filters for separation of metal precipitates. Sulfate was not tracked through individual unit operations. The five bag filters combined separated 20.7 kg of metals from solution, allowing 127.3 kg of soluble metals, metal precipitate, and undissolved

Table 2-18. Alkaline Lagoon Unit Operation Reaction Chemistry

Parameter	Unit	System Influent	Reactor No. 1	Reactor No. 2	Reactor No. 3	Reactor Change	System Effluent	System Change
pH	(SU)	4.59	8.05	8.18	8.02	3.5	7.92	3.33
Redox Potential	(mV)	188	188	190	190	2	190	2
Total Iron (dissolved)	(mg/L)	394	NM	NM	1.5	-392.5	0 463	-393.5
Ferrous Iron	(mg/L)	6.75	NM	NM	0.7	-6	0	-6.75
Specific Conductance	(µmhos/cm)	2,665	2,840	2,820	2,790	125	3,000	335
Dissolved Oxygen	(mg/L)	1.6	1.8	4 6	6	4.4	6.6	5.0
Temperature	(°C)	14.8	12.94	12.43	12.73	-2.1	18.07	3.27
Sulfate	(mg/L)	1,900	NM	NM	NM	NC	2,040	140
Total Alkalinity	(mg/L)	< 2	NM	NM	NM	NC	69.1	68.1
Total Dissolved Solids	(mg/L)	2,660	NM	NM	NM	NC	2,910	250

Parameter	Unit	Bag Filter Influent	Bag Filter Effluent	Filter Change	Lagoon Cell No. 1	Lagoon Cell No. 2	Lagoon Cell No. 3	Lagoon Change
pH	(SU)	8.02	7.93	-0.1	7.9	7.9	7.92	0.02
Redox Potential	(mV)	190	190	0	189	189	190	1
Total Iron	(mg/L)	1.5	18	16.5	2.4	0.462	0.463	-1.94
Ferrous Iron	(mg/L)	0.7	0.2	-0.5	< 0.1	< 0.1	< 0.1	0
Specific Conductance	(µmhos/cm)	2,790	2,810	20	2,950	2,990	3,000	50
Dissolved Oxygen	(mg/L)	6	5.34	-0.66	NM	NM	6.6	NC
Temperature	(°C)	12.73	17.96	5.23	17.06	17.55	18.07	1.01
Sulfate	(mg/L)	NM	NM	NC	NM	NM	2,040	NC
Total Alkalinity	(mg/L)	NM	NM	NC	NM	NM	69.1	NC
Total Dissolved Solids	(mg/L)	NM	2,840	NC	NM	NM	2,910	NC

µmhos/cm = Micromhos per centimeter
°C = Degree Celsius
mV = Millivolt
mg/L = Milligram per liter
NC = Not calculated
NM = Not measured
SU = Standard unit

Table 2-19. Alkaline Lagoon Unit Operation Metals Removal Efficiencies

Parameter	Reaction Tanks			Bag Filters		Lagoon		System	
	Influent (µg/L)	Effluent (µg/L)	Removal Efficiency (%)	Effluent (µg/L)	Removal Efficiency (%)	Effluent (µg/L)	Removal Efficiency (%)	Effluent (µg/L)	Removal Efficiency (%)
Aluminum	33,600	470	98.60	2,100	-77.62	254	87.90	254	99.24
Arsenic	510	9.7	98.10	34 0	-71.47	5.8	82.94	5.8	98.86
Cadmium	< 0.3	< 0.3	0.00	0.3	-50.00	0 3	0.00	0.3	-50.00
Chromium	19.5	3.5	82.05	4 6	-23.91	3.3	28.26	3.3	83.08
Copper	14 0	4.8	65.71	2.5	92.00	3.6	-30.56	3.6	74.29
Iron	394,000	1,500	99.62	18,000	-91.67	463	97.43	463	99.88
Lead	5.1	< 1.2	88.24	1.5	-60.00	< 1.2	60.00	< 1.2	88.24
Nickel	1,670	64.1	96.16	129	-50.31	22.4	82.64	22.4	98.66
Selenium	< 2.5	< 2.5	0.00	< 2 5	0.00	< 2.5	0.00	< 2.5	0.00
Zinc	360	14 1	96.08	32.2	-56.21	9.6	70.19	9.6	97.33

% = Percent µg/L = Microgram per liter

hydrated lime to discharge to the alkaline lagoon for additional reaction and final settling. A total of 97.9 kg of metals (primarily calcium) and 232.4 kg of sulfate were batch discharged from the alkaline lagoon to Leviathan Creek. A total of 89 kg of solids were captured in the five bag filters; while an additional 29 kg of solids settled in the alkaline lagoon. A total of 185.8 kg of hydrated lime was required to neutralize 65.9 kg acidity (as hydrated lime) and precipitate 53.6 kg of metals (excluding added calcium) from the ARD on July 30, 2002.

2.5.4.4 Solids Separation

Precipitate generated during operation of the semi-passive alkaline lagoon treatment system is separated from ARD using bag filters and a settling lagoon with extended hydraulic residence time. The bag filtration process is used to capture the majority of the solids prior to discharge to the settling lagoon. Solids handling following treatment is simplified using bag filters in comparison to draining the settling lagoon, air drying the sludge, and excavating the sludge from the HDPE-lined basin. The bag filters removed between 52 and 79 percent of the metals and 58 percent of suspended solids from solution prior to filtrate discharge to the settling lagoon.

Extended lime dissolution and reaction with residual metals and settling in the lagoon promoted removal of 54 to 99 percent of metals and suspended solids from solution. Effluent from the settling lagoon met EPA discharge criteria. Neither solids separation approach was as effective as the combination of polymer addition and settling in plate and pit clarifiers. Additional suspended solids removal could be achieved by adding a polymer to the final reaction tank to improve floc growth rate and size. Metals and solids removal efficiencies for bag filters and settling lagoon are provided in Table 2-20.

Up to five bag filters were used at one time to remove the initial load of suspended solids from the ARD slurry. The HRT of each bag filter varies based on the thickness of the

Table 2-20. Alkaline Lagoon Solids Separation Efficiencies

Parameter	Bag Filter				Lagoon			Cumulative Percent Removal (%)
	Unfiltered Influent (µg/L)	Unfiltered Effluent (µg/L)	Percent Removal (%)	Separated Solids (mg/kg)	Unfiltered Influent (µg/L)	Unfiltered Effluent (µg/L)	Percent Removal (%)	
Aluminum	31,500	10,200	67.62	20,000	10,200	307	96.99	99.03
Arsenic	508	164	67.72	326	164	7.2	95.61	98.58
Cadmium	< 0.3	<0.3	0.00	< 0.52	<0.3	< 0.3	0.00	0.00
Chromium	24.9	11.8	52.61	19.9	11.8	3.8	67.80	84.74
Copper	29.7	8 7	70.71	9.4	8.7	4.0	54.02	86.53
Iron	322,000	99,900	68.98	205,000	99,900	932	99 07	99.71
Lead	7.8	1.6	79.49	3.1	1.6	<1.2	62.50	92.31
Nickel	1,490	506	66.04	924	506	27.2	94.62	98 17
Selenium	< 2.5	< 2.5	0.00	5.9	< 2.5	< 2.5	0.00	0.00
Zinc	343	117	65.89	213	117	11.4	90.26	96.68
TSS	1,100,000	456,000	58.55	NA	456,000	10,000	97.81	99.09

% = Percent mg/kg = Milligram per kilogram
µg/L = Microgram per liter NA = Not applicable

filter cake buildup on the bag interior. A fresh bag filter with minimal filter cake build up provides approximately 5.3 hours of HRT at one-fifth the treatment rate, while a full bag provides less than 1 hour of HRT. Approximately 113,000 liters of ARD slurry was discharged to up to five bag filters each day, generating a total of 89 kg of dry solids. On average, the bag filters fill with solids and require change out every 60 days. Approximately 1 day is required to obtain adequate filtration from a new bag. A total of nine bag filters were used over 128 days of operation. The bag filters were allowed to gravity drain and air dry to a moisture content of 88 percent prior to solids handling. The bag filters were cut open, the contents removed with a bobcat, and transferred to a roll off bin for disposal.

The settling lagoon provided an average of 16.7 days of HRT for dissolution and reaction of any remaining lime with metals and solids settling. Approximately 113,000 liters of filtrate was discharged from the bag filters to the settling lagoon each day, generating approximately 29 kg of dry solids. On average, 9 to 18 centimeters of wet sludge (98 to 99 percent moisture content) is deposited in the settling lagoon during a treatment season. Sludge has not been removed from the settling lagoon to date due to the small quantity generated.

2.5.5 Evaluation of Solids Handling and Disposal

The following sections describe solids handling activities conducted during the operation of each treatment system. The discussion includes a summary of waste characterization and handling requirements, identifies the sources and quantity of solids from each treatment system, identifies the characteristics of each solid waste stream, and identifies the method of disposal for each solids waste stream.

2.5.5.1 Waste Characterization and Handling Requirements

Lime treatment of AMD and ARD generates a metal hydroxide solid waste stream. The solid waste residuals produced by both treatment systems were analyzed for hazardous waste characteristics. Determination of waste characteristics is necessary to determine appropriate handling and disposal requirements. Therefore, total and leachable metals analyses were performed on the solid waste streams for comparison to California and Federal hazardous waste classification criteria. To determine if the solid waste streams are a Federal Resource Conservation and Recovery Act (RCRA) waste, TCLP results were compared to TCLP limits. To determine whether the solid waste streams are a California hazardous waste, total metals results (wet weight) were compared to California total threshold limit concentration (TTLC) criteria. If a solid waste stream exceeds either Federal TCLP criteria or California TTLC criteria, then the waste is considered to be hazardous and must be disposed of in a permitted TSD facility.

If a solid waste stream is found to be non-hazardous, then the potential to impact water quality must be evaluated. The leachability of metals from a solid waste stream must be determined using the California WET procedure if disposed of in California or another accepted leaching procedure if disposed of in other states. Deionized water (DI) was used as the WET leaching solution. To determine whether a non-hazardous solid waste stream poses a threat to water quality in California, metals concentrations in WET leachate samples were compared to California soluble threshold limit concentration (STLC) criteria. Solid waste stream samples were also subject to the SPLP, a commonly accepted leaching procedure in other states. If a solid waste stream exceeds the California STLC criteria, then the waste is considered to be a threat to water quality and the waste must be disposed of in a permitted TSD facility or engineering controls implemented to protect water quality. Interpretation of SPLP data are state-specific and are beyond the scope of this discussion. Evaluation of the quantity, characteristics, and disposal of solid waste streams generated by the active lime treatment system is presented in Section 2.5.5.2 and the semi-passive alkaline lagoon treatment system in Section 2.5.5.3.

2.5.5.2 Active Lime Treatment System

Biphasic operation of the active lime treatment system in 2002 and 2003 produced 44 dry tons of filter cake (54.6 to 63.1 percent moisture) for Phase I of the process and 212 dry tons (77 to 84.4 percent moisture) of metal hydroxide sludge in the Phase II pit clarifier. The Phase I filter cake consists mainly of iron and arsenic hydroxides; while the Phase II pit clarifier sludge consists of gypsum and metal hydroxides high in iron, aluminum, copper, nickel, and zinc. During monophasic operations in 2003, the active lime treatment system produced 15.2 dry tons (75.9 percent moisture) of filter cake consisting of gypsum and metal hydroxides high in iron, aluminum, arsenic, copper, nickel, and zinc. No other waste streams were generated during monophasic operations.

The characteristics of the solid waste streams generated during biphasic and monophasic operations in 2003 are presented in Table 2-21. The Phase I filter cake generated during biphasic operations in 2002 and 2003 was determined to be a California hazardous waste by RWQCB due to elevated arsenic concentrations. However, our evaluation data indicate that arsenic was slightly below the State TTLC criteria and was not a hazardous waste. RWQCB shipped the filter cake off-site to a permitted TSD facility in Beatty, Nevada. The Phase II pit clarifier sludge generated during biphasic operations in 2002 and 2003 was found to be a non-hazardous waste. The non-hazardous sludge was excavated from the pit clarifier prior to

Table 2-21. Active Lime Treatment System Waste Characterization

Parameter	Total Metals[1]	Total Metals[2] (mg/kg)	Exceed TTLC?	DI WET Metals (mg/L)	Exceed STLC?	TCLP (mg/L)	Exceed TCLP?	SPLP Metals (mg/L)
Biphasic Phase I Filter Cake								
Antimony	< 1.4	< 0.52	No	< 0.013	No	< 0.005	NA	< 0.0025
Arsenic	1,300	478	No	0.448	No	< 0.0063	No	Rejected
Barium	2	0.74	No	0.0292	No	0.0166	No	0.0035
Beryllium	0.72	0.266	No	0.0211	No	< 0.00016	NA	<0.000077
Cadmium	2.6	0.96	No	< 0.0054	No	0.0054	No	0.0017
Chromium	222	81.9	No	2.87	No	< 0.0031	No	Rejected
Cobalt	62 9	23.2	No	1.92	No	0.159	NA	<0.00061
Copper	125	46.1	No	2.81	No	< 0.0149	NA	< 0.0117
Lead	1.8	0.66	No	0.0082	No	0.0086	No	0.0151
Mercury	0.018	0.007	No	< 0.000025	No	<0.000025	No	< 0.000025
Molybdenum	< 0.46	< 0.17	No	< 0.0042	No	< 0.003	NA	< 0.00084
Nickel	184	67.9	No	5.58	No	0.671	NA	0.0045
Selenium	< 0.81	< 0.299	No	< 0.0075	No	< 0.003	No	< 0.0015
Silver	1.2	0 44	No	0.0055	No	< 0.0097	No	< 0.0058
Thallium	2.8	1.03	No	< 0.0314	No	0.0284	NA	0.0168
Vanadium	49.4	18.2	No	0.266	No	<0.00076	NA	< 0.00038
Zinc	43.2	15 9	No	1.17	No	0.0247	NA	0.0128
Biphasic Phase II Pit Clarifier Sludge								
Antimony	< 32	< 5	No	< 0.050	No	< 0.020	NA	< 0.010
Arsenic	224	34.9	No	0.522	No	< 0.0038	No	< 0.0028
Barium	4.2	0.66	No	0.0347	No	< 0.0202	No	< 0.0052
Beryllium	5.6	0.87	No	0.0744	No	< 0.00027	NA	< 0.002
Cadmium	21.4	3.34	No	0.188	No	0.0351	No	< 0.002
Chromium	242	37.8	No	3	No	0.0268	No	< 0.0037
Cobalt	1,100	172	No	13.5	No	0.638	NA	< 0.0021
Copper	837	131	No	9.2	No	0.0257	NA	< 0.0022
Lead	4 2	0.66	No	< 0.0349	No	<0.0033	No	< 0.004
Mercury	0.12	0.019	No	0.000059	No	0.000037	No	0.000071
Molybdenum	< 1.3	< 0.203	No	< 0.025	No	< 0 010	NA	< 0.005
Nickel	2,670	417	No	30.6	**Yes**	2.91	NA	<0.0072
Selenium	< 3.2	< 0.5	No	< 0.0477	No	< 0.0152	No	< 0.010
Silver	< 3.2	< 0.5	No	<0 0139	No	<0.010	No	< 0.0056
Thallium	9.9	1.54	No	0.143	No	0.0523	NA	0.031
Vanadium	10.9	1.7	No	0.0734	No	< 0.020	NA	< 0.010
Zinc	573	89.4	No	6.78	No	0.165	NA	< 0.012
Monophasic Filter Cake								
Antimony	< 2	< 0.48	No	<0.0704	No	< 0.0129	NA	< 0.0039
Arsenic	2,510	605	**Yes**	28.8	**Yes**	< 0.0161	No	< 0.0019
Barium	8.7	2.1	No	0.119	No	0 0257	No	< 0.0037
Beryllium	5.1	1.2	No	0.101	No	< 0.00038	NA	< 0.00019
Cadmium	25.7	6.2	No	0.373	No	< 0.0046	No	< 0.00016
Chromium	244	58.8	No	4.25	No	< 0.0029	No	< 0.00054
Cobalt	858	207	No	14.5	No	0.577	NA	< 0.0018
Copper	373	89.9	No	6.82	No	< 0.016	NA	< 0.0019
Lead	5.9	1.4	No	0.086	No	< 0.0059	No	< 0.0009
Mercury	0.17	0.041	No	0.00029	No	< 0.00019	No	< 0.00013
Molybdenum	< 0.4	< 0.096	No	< 0 0024	No	< 0.00097	NA	< 0.00048
Nickel	1,990	480	No	33.5	**Yes**	1.43	NA	< 0.0029
Selenium	21.6	5.2	No	<0.140	No	< 0.0372	No	< 0.0026
Silver	< 0.36	< 0.087	No	< 0.0022	No	< 0.0034	No	< 0.00075
Thallium	74.1	17.9	No	0.935	No	0.272	NA	0.0859
Vanadium	150	36.2	No	1.83	No	< 0.0011	NA	< 0.00053
Zinc	397	95.7	No	5.5	No	0.0599	NA	< 0.002

[1] Metals data reported as dry weight

[2] Metals data reported as wet weight for comparison to TTLC

DI WET = Waste extraction test using deionized water
mg/kg = Milligram per kilogram
mg/L = Milligram per liter
NA = Not applicable

SPLP = Synthetic precipitation leaching procedure
STLC = Soluble threshold limit concentration
TCLP = Toxicity characteristic leaching procedure
TTLC = Total threshold limit concentration

2003 operations and disposed of on site after it was determined not to pose a threat to water quality. The solids generated in 2003 were found to pose a threat to water quality due to leachable concentrations of nickel exceeding State STLC criteria. The sludge remains in the pit clarifier awaiting future excavation and on-site storage after stabilization. The filter cake generated during monophasic operations in 2003 was determined to be a California hazardous waste due to elevated arsenic concentrations. The filter cake was shipped off-site to a permitted TSD facility in Beatty, Nevada.

2.5.5.3 Semi-Passive Alkaline Lagoon Treatment System

The semi-passive alkaline lagoon treatment system produced an estimated 12.6 dry tons of bag filter solids (88.4 percent moisture). The bag filter solids consist mainly of aluminum, iron, and manganese hydroxides, gypsum, and a significant quantity of arsenic, cobalt, and nickel hydroxides. An estimated 4.1 dry tons of sludge (98 percent moisture) was settled in the lagoon; however, a sample for waste characterization was not collected due to the small amount generated.

The bag filter solids generated during 2002 operations were determined to be non-hazardous and not a threat to water quality. The solids were shipped off-site to a municipal landfill for disposal. The characteristics of the solid waste stream generated during 2002 operations are presented in Table 2-22.

Table 2-22. Semi-Passive Alkaline Lagoon Treatment System Waste Characterization

	Bag Filter Solids							
Parameter	Total Metals[1] (mg/kg)	Total Metals[2] (mg/kg)	Exceed TTLC?	DI WET Metals (mg/L)	Exceed STLC?	TCLP (mg/L)	Exceed TCLP?	SPLP Metals (mg/L)
Antimony	< 6.2	< 0.72	No	< 0.018	No	< 0.0072	NA	< 0.0036
Arsenic	326	37.8	No	3.14	No	< 0.003	No	< 0.0017
Barium	< 4.5	< 0.52	No	0.113	No	< 0.0067	No	< 0.0066
Beryllium	3.6	0.42	No	0.0325	No	< 0.0003	NA	< 0.0002
Cadmium	< 0.52	< 0.06	No	< 0.0015	No	< 0.00058	No	< 0.00029
Chromium	19.9	2.3	No	0.151	No	< 0.013	No	< 0.0043
Cobalt	449	52.1	No	4.37	No	0.105	NA	< 0.0035
Copper	9.4	1.1	No	< 0.067	No	< 0.0048	NA	< 0.0062
Lead	3.1	0.36	No	0.0401	No	< 0.0028	No	< 0.0019
Mercury	0.25	0.029	No	0.000038	No	0.00003	No	0.000028
Molybdenum	< 1.7	< 0.197	No	< 0.0049	No	< 0.0019	NA	< 0.0017
Nickel	924	107	No	8.9	No	0.278	NA	0.0053
Selenium	5.9	0.68	No	0.0788	No	< 0.0141	No	< 0 0055
Silver	< 0.96	< 0.111	No	< 0.0201	No	< 0.0066	No	< 0.00062
Thallium	< 2.6	< 0.30	No	< 0.0075	No	< 0.0105	NA	< 0 0047
Vanadium	28	3.3	No	0.246	No	0.0013	NA	< 0.00066
Zinc	213	24.7	No	2.27	No	0.0187	NA	0.0215

[1] Metals data reported as dry weight

[2] Metals data reported as wet weight for comparison to TTLC

DI WET = Waste extraction test using deionized water
mg/kg = Milligram per kilogram
mg/L = Milligram per liter
NA = Not applicable
SPLP = Synthetic precipitation leaching procedure
STLC = Soluble threshold limit concentration
TCLP = Toxicity characteristic leaching procedure
TTLC = Total threshold limit concentration

SECTION 3
TECHNOLOGY APPLICATIONS ANALYSIS

This section of the ITER describes the general applicability of the lime treatment technologies to reduce acidity and toxic levels of metals in water at AMD- and ARD-contaminated mine sites. The analysis is based on the results from and observations made during the SITE demonstration.

3.1 Key Features

Oxidation of sulfur and sulfide minerals within the mine workings and waste rock forms sulfuric acid (H_2SO_4), which liberates toxic metals from the mine wastes creating AMD and ARD. Lime treatment of AMD and ARD is a relatively simple chemical process where low pH AMD/ARD is neutralized using lime to precipitate dissolved iron, the main component of AMD and ARD, and other dissolved metals as metal hydroxides and oxy-hydroxides. The precipitation occurs under the following reaction:

$$Ca(OH)_{2\,(s)} + Me^{2+}/Me^{3+}{}_{(aq)} + H_2SO_4 \rightarrow Me(OH)_2/Me(OH)_{3\,(s)} + CaSO_{4\,(s)} + H_2O \qquad (1)$$

Where: Me^{2+}/Me^{3+} = dissolved metal ion in either a +2 or +3 valence state

Along with metal hydroxides, excess sulfate combines with excess calcium to precipitate gypsum. Lime treatment can occur in a single stage or multiple-stage process, depending on the need to reduce the quantity of solids requiring handling and disposal as a hazardous waste in an off-site TSD facility.

The active lime treatment system can be used to reduce acidity and precipitate toxic metals using either a single stage (monophasic) or dual stage (biphasic) lime addition process, as demonstrated at the Leviathan Mine site. In monophasic mode, the pH of the acid mine flow is raised to precipitate out all of the target metals resulting in a large quantity of hazardous metals-laden sludge. During biphasic operations, the active lime treatment system creates a small quantity of hazardous metals-laden filter cake from the first precipitation phase (Phase I). The optimum pH range for Phase I precipitation is between 2.8 and 3.0. In the second precipitation phase (Phase II), the pH is further raised through lime addition to precipitate out the remaining target metals forming a large quantity of non-hazardous sludge. The optimum pH range for Phase II precipitation is between 7.9 and 8.2. The Phase II sludge typically does not exhibit hazardous waste characteristics because the majority of the hazardous metals were removed in Phase I. The biphasic configuration of the active lime treatment system utilizes the same equipment as the monophasic configuration, though operated in a two-step lime addition process, and includes the addition of an extended settling pit clarifier.

The semi-passive alkaline lagoon treatment system, also demonstrated at Leviathan Mine, can be used to reduce acidity and precipitate toxic metals using the same reaction chemistry as the active lime treatment system. The system relies on iron oxidation during mechanical aeration, optimization of lime dosage, and adequate cake thickness within each bag filter to filter precipitate from the treated ARD. The system also includes a multi-cell settling lagoon for extended lime contact and final precipitation of pin floc.

3.2 Applicable Wastes

Conventional methods of treating AMD and ARD involve the capture, storage, and batch or continuous treatment of water using lime addition, which neutralizes acidity and precipitates metals. Lime treatment is applicable to any waste stream containing metals, if the solubility of the metals is pH-sensitive. Metals typically treated include aluminum, arsenic, cadmium, chromium, copper, iron, lead, nickel, and zinc. The active lime and semi-passive alkaline lagoon treatment systems in operation at the Leviathan Mine site are simply improvements to conventional lime treatment technology. Either treatment system can be modified to treat wastes of varying metals type or concentration in a single or multi-stage process. Active lime treatment appears to be applicable in situations where flow rates are high and the treatment season is short, while the semi-passive alkaline treatment lagoon favors a lower flow rate and extended treatment season. Where climate is a limiting factor, an active lime treatment

system can be housed in a structure heated to temperatures above freezing.

3.3 Factors Affecting Performance

Several factors can influence the performance of the lime treatment systems demonstrated at Leviathan Mine. These factors can be grouped into two categories: (1) mine drainage characteristics, and (2) operating parameters. Both lime treatment technologies are capable of treating a broad range of metals in AMD and ARD. The level of acidity, ionic strength, and metals composition directly impact the quantity and timing of lime delivery required to neutralize acidity and precipitate target metals. The quantity of lime required to neutralize acidity is often greater than the hydroxide ion required for metals precipitation. Increases in solution ionic strength, often driven by iron and aluminum content, requires additional lime for target metals precipitation. Finally, careful control of lime addition is required above neutral pH to prevent dissolution of target metals back into solution. System design should include an AMD/ARD equilibration basin upstream of the treatment system to reduce fluctuations in acidity and solution ionic strength, allowing system operators to more tightly control reaction chemistry.

Unit operating parameters also directly impact system performance. The quality of lime, lime dose, duration of lime contact, pH control, and HRT all impact removal of target metals. Variations in the quality of lime used, poor lime feed design, and inadequate maintenance can lead to formation of caked lime within the lime slurry holding tank and the lime feed pumps and delivery lines. Careful design, operation, and maintenance of lime storage tanks, pumps, delivery lines, and pH process monitoring probes is required to maintain stable lime dosing rates and maximize system up time. A higher purity lime should also be used to improve pumpability and minimize maintenance. Lime overdosing can lead to excessive scaling problems inside of reaction tanks, clarifiers, pumps, and piping; while inadequate dosing can lead to excess metals in the effluent streams that exceed discharge standards.

The method and duration of lime contact with AMD and ARD in the reaction tanks also impacts system performance due to incomplete lime dissolution, inadequate hydroxide contact with target metals, and inadequate time required for precipitate formation and growth. Careful sizing, design, and maintenance of mixing devices such as aeration bars and stirrers is required to ensure adequate lime dissolution and contact with AMD and ARD. System operators must also balance system influent flow rate, solids recycle rate, and mixing rate to allow adequate time for precipitate growth.

Finally, the method and duration of precipitate separation and settling also impacts system performance due to the extended time required for complete lime dissolution and the settling of pin floc. The active lime treatment system relies on a flocculent to generate settleable solids, plate clarifiers to concentrate settled solids, and a large pit clarifier to allow settling of pin floc. If flocculent dosage is not adequately controlled or system influent flow rates vary, then the efficiency of the plate clarifiers decreases. Therefore, a large extended settling basin, such as the pit clarifier, provides the system operator some room for error during system upsets. The semi-passive alkaline lagoon treatment system relies on bag filters to separate precipitate and a lagoon to allow extended lime dissolution, contact with soluble target metals, and settling of pin floc. The bag filters remove 40 to 60 percent of the precipitates, while the lagoon removes the remaining precipitates and allows the system operator some room for error during system upsets.

3.4 Technology Limitations

In general, the limitations of the lime treatment systems implemented at Leviathan Mine were not related to the applicability of the technology, but rather to operational issues due to weather conditions, maintenance problems, and remoteness of the site. Because of sub-freezing temperatures encountered in the high Sierras during winter months, the Leviathan Mine lime treatment systems were shut down from late fall through late spring. The systems were completely drained and winterized to prevent damage to pumps, tanks, and system piping. The process of winterizing and de-winterizing either treatment system is time consuming and manpower intensive. The State and ARCO are currently evaluating the feasibility of constructing an active lime treatment system, enclosed within a heated shelter, for long term year round operations. Year round operational capability would allow downsizing of the treatment system for lower continuous flow rates rather than large batch flow rates.

Lime treatment systems are maintenance intensive and have to be monitored regularly to maintain proper operating conditions. During extended operation, lime storage tanks, reaction tanks, lime transfer and process water pumps, feed and transfer piping, and process monitoring probes are susceptible to plugging with lime clumps and gypsum scaling. During operation of the lime treatment systems at Leviathan Mine, on several occasions sections of piping were replaced, pumps were upgraded, and monitoring devices were replaced due to gypsum fouling. Continued optimization of lime dosage and equipment improvements would likely reduce downtime associated with lime and gypsum fouling.

The remoteness of the site also created logistical challenges in maintaining operation of the lime treatment systems. Consumable materials, such as lime and diesel fuel (to power generators), were stored in bulk at the site. In one instance, a shipment of lime had to be diverted to a secondary route because of traffic issues; the diversion resulted in a half-day delay in the delivery of the lime. During operation of the treatment systems in early fall and late spring, unexpected freezing temperatures can cause pipe breakage. In addition,

early and late snowfall events can prevent site access. Careful planning is essential to maintain supplies of consumable materials and replacement equipment at remote sites.

3.5 Range of Suitable Site Characteristics

This section describes the site characteristics necessary for successful application of either lime treatment technology.

Staging Area and Support Facilities: For full-scale lime treatment systems such as those in operation at Leviathan Mine, substantial staging areas and support facilities are necessary for continuous operation of the treatment systems. A staging area is needed for storage of consumable materials, supplies, and reagents; loading and unloading equipment; and for placement of Connex boxes, which are used for storage of spare parts and equipment that are not weather resistant. Additional space is necessary for placement of portable office, laboratory, and health and safety facilities; portable toilets; and power generating equipment. The staging and facilities areas for a large treatment system may range between 1,000 and 4,000 square meters and are usually located near or adjacent to the treatment system and holding ponds. These areas should include pass-through access roads to accommodate large tractor-trailer rigs that are used to drop off and pickup equipment and facilities.

Treatment System Space Requirements: For the active lime treatment system, space is needed for reagent storage tanks, make-up water tanks, reaction tanks, clarifiers, floc mix tanks, sludge holding tanks, a filter press, and various pumps and piping. The sizing of equipment and the space necessary for these systems is dependent on the flow rate of the ARD or AMD to be treated. Additional level land may be necessary for holding ponds, particularly if the systems are run seasonally rather than year round. Overall, the space requirement for the active lime treatment system at Leviathan Mine is about 800 square meters. A pit clarifier, which requires an additional 1,400 square meters of space, may be necessary during biphasic operations.

For the alkaline lagoon treatment system, about 1,000 square meters is needed for placement of reagent storage tanks, reaction tanks, air compressors, bag filters, and various pumps and piping. A large extended contact settling lagoon, capable of containing at least 3 days worth of partially treated ARD, is also required. The settling lagoon at Leviathan Mine covers about 4,000 square meters and has a total volume of 5.4 million liters.

Climate: Operation of the lime treatment systems may be affected by various climatological effects such as precipitation, snowfall, and freezing temperatures. If holding ponds are utilized to accumulate water for treatment, excessive rainfall will likely increase the overall volume of water to be treated; however, this may be offset by summer evaporation. Water storage tanks may be necessary at sites where excessive rainfall is expected, and evaporation rates are low. Although limited snowfall will not generally affect operating conditions, excessive snowfall may lead to freezing of pipes and other process equipment resulting in significant down-time. In areas where freezing temperatures are normal throughout the winter months, such as at the Leviathan Mine site, the lime treatment system must be completely drained and winterized to prevent damage to pumps, tanks, and system piping. The process of winterizing and de-winterizing either treatment system is time consuming and manpower intensive. Consideration should also be given to constructing a heated shelter for treatment systems located at high altitude or in areas with freezing temperatures to avoid labor costs associated with winterization/dewinterization activities. Other climatological effects such as wind and excessive heat do not generally have an affect on the operation of the systems; however, additional precautions should be observed during these conditions to protect the operator health and safety.

Utilities: The main utility requirement for a lime treatment system is electricity, which is used to operate electrical and hydraulic pumps, stirrer motors, air compressors, process monitoring equipment, portable office trailers, and site lighting. Each lime treatment system at Leviathan Mine requires up to 20 kilowatt (kW)-hours of electricity for continuous operation. The main generators run continuously during operation of both treatment systems. For the active lime treatment system, a 180 kW diesel generator (including a 4,000-liter diesel fuel tank) is used to power the treatment system and support facilities. A 150 kW diesel generator (including a 4,000-liter diesel fuel tank) is used to power the semi-passive alkaline lagoon treatment system and support facilities. A spare 45 kW backup unit (with a 1,400-liter diesel fuel tank) is also located onsite. Depending on the remoteness of the site, cellular or satellite phone service may be required.

3.6 Personnel Requirements

Personnel requirements for operation of each treatment system following initial design and construction can be broken down into the following activities: seasonal assembly, startup, and shakedown; operation and maintenance; and seasonal demobilization. System start-up and shakedown includes the labor to setup pumps, pipes, and rental equipment, test system hydraulics, startup the system, and optimize the system to meet discharge standards. System startup and shakedown occurs at the beginning of each treatment season as the system is cleaned and disassembled each winter. After system assembly and start up, a shake down is necessary to ensure that any problems are identified and addressed prior to optimization. The system is then optimized for the desired source water, flow rate, and discharge standards. This process generally requires 8 to 10 days of labor for a field crew of four who are familiar with the system. After initial startup, a

significant amount of additional time may be spent refining lime and polymer dosages and for hydraulic balancing.

Field personnel are necessary to operate each treatment system, perform daily maintenance, drop waste solids from the filter press, collect discharge monitoring samples, monitor unit operation pH and flow rates, and to adjust lime and polymer dosage rates. The active lime treatment system, operated in both monophasic and biphasic modes, require a minimum of two personnel per shift and from two to three shifts per day depending on stability of operations and maintenance requirements. The semi-passive alkaline lagoon treatment system requires a minimum of two personnel per day to ensure proper operation and maintain equipment. This system requires fewer personnel due to fewer, less complicated unit operations.

Demobilization includes cleaning, disassembling, and storing system components at the end of each treatment season. Demobilization activities include draining unused reagents from the system, cleaning the interior of reaction tanks, lime slurry tanks, and clarifiers; disassembly, cleaning, and storage of pumps and piping; returning of rental equipment; and consolidation and off-site disposal of hazardous waste. This process generally requires 8 to 10 days of labor for a field crew of four who are familiar with the system.

In addition to field personnel, support staff is required for project management, site management, engineering, and administrative support functions. The level of effort required for support staff ranges from 20 to 40 percent of the total project level of effort, depending on the duration of the treatment season.

3.7 Materials Handling Requirements

There is one process residual associated with lime treatment of AMD and ARD. The process produces a large quantity of metal hydroxide sludge and filter cake. During operation in biphasic mode, the active lime treatment system produced about 43.8 dry tons of Phase I filter cake consisting mainly of iron and arsenic hydroxides and 212 dry tons of Phase II pit clarifier sludge consisting of metal hydroxides high in iron, aluminum, copper, nickel, zinc, and lime solids. In addition, gypsum is also a large component of the Phase II sludge. During operation in monophasic mode, the active lime treatment system produced about 15.2 dry tons of filter cake consisting of metal hydroxides and gypsum. The semi-passive alkaline lagoon treatment system produced 12.6 dry tons of bag filter sludge consisting of metal hydroxides and gypsum.

The solid waste residuals produced by the treatment systems were analyzed for hazardous waste characteristics. Total metals and leachable metals analyses were performed on the solid wastes for comparison to California and Federal hazardous waste classification criteria. To determine whether the residuals are California hazardous waste, total metals results were compared to TTLC criteria. To determine whether metals concentrations in the solid waste residuals pose a threat to water quality, DI WET leachate results were compared to STLC criteria. To determine if the residuals are a RCRA waste, TCLP leachate results were compared to TCLP limits. The hazardous waste characteristics determined for the solid waste streams are presented in Table 3-1.

The Phase I filter cake generated during biphasic operations was determined to be a California hazardous waste due to elevated arsenic concentrations. The Phase II pit clarifier sludge generated during biphasic operations was found to be a threat to water quality due to leachable concentrations of nickel exceeding State STLC criteria. The filter cake generated during monophasic operations was determined to be a California hazardous waste due to elevated arsenic concentrations. The bag filter solids generated during operation of the alkaline lagoon treatment system did not exceed any of the waste classification criteria. With the exception of the Phase II pit clarifier sludge produced in 2003, the solid waste streams that failed the TTLC, STLC, or TCLP criteria were transported to an off-site TSD facility for disposal. Solid waste streams that passed both State and Federal hazardous waste criteria were disposed of on site.

3.8 Permit Requirements

Actions taken on-site during a CERCLA cleanup action must comply only with the substantive portion of a given regulation. On-site activities need not comply with administrative requirements such as obtaining a permit, record keeping, or reporting. Actions taken off-site must comply with both the substantive and administrative requirements of applicable laws and regulations. All actions taken at the Leviathan Mine Superfund site were on-site; therefore permits were not obtained.

Permits that may be required for off-site actions or actions at non-CERCLA sites include: a permit to operate a hazardous waste treatment system, an National Pollutant Discharge and Elimination System (NPDES) permit for effluent discharge, an NPDES permit for discharge of storm water during construction activities, and an operations permit from a local air quality management district (AQMD) for activities generating particulate emissions. Permits from local agencies may also be required for grading, construction, and operational activities; transport of oversized equipment on local roads; and transport of hazardous materials on local roads.

3.9 Community Acceptance

Community acceptance for the lime treatment systems operated at Leviathan Mine is positive. The diversion and treatment of AMD and ARD at the mine site is seen as

Table 3-1. Determination of Hazardous Waste Characteristics for Solid Waste Streams at Leviathan Mine

Treatment System	Mode of Operation	Operational Year	Solid Waste Stream Evaluated	Total Solid Waste Generated	TTLC Pass or Fail	STLC Pass or Fail	TCLP Pass or Fail	Waste Handling Requirement
Active Lime Treatment System	Biphasic	2002	Phase I Filter Cake	22 7 dry tons	F	F	P	Off-site TSD Facility
			Phase II Pit Clarifier Sludge	118 dry tons	P	P	P	On-site Disposal
		2003	Phase I Filter Cake	21.1 dry tons	F	P	P	Off-site TSD Facility
			Phase II Pit Clarifier Sludge	93.6 dry tons	P	F	P	On-site Storage
	Monophasic	2003	Filter Cake	15.2 dry tons	F	F	P	Off-site TSD Facility
Semi-passive Alkaline Lagoon Treatment System		2002	Bag Filter Sludge	12.6 dry tons	P	P	P	On- or Off-site Disposal

STLC = Soluble threshold limit concentration TSD = Treatment, storage, and disposal
TTLC = Total threshold limit concentration TCLP = Toxicity characteristic leaching procedure

necessary and positive step towards reestablishing a quality watershed within the Sierra Nevada mountain range. Although ARD is returned to Leviathan Creek during the winter months because reliable power is not available to lift ARD from the bottom of the mine site to the retention ponds, the community, EPA, ARCO, and the state of California are evaluating options to ensure that ARD is removed from Leviathan Creek year round. Continued community involvement and regulatory agency support will be necessary for long term treatment and monitoring at a mine site such as Leviathan Mine.

Operation of the lime treatment system presents minimal to no risk to the public since all system components and treatment operations occur within a contained site. Hazardous chemicals used in the treatment system include lime and diesel fuel. In addition, hazardous solids in the form of metal hydroxide filter cake are generated during the treatment process. These chemicals pose the highest risk to the public during transportation to and from the site by truck and trailer. Appropriate Department of Transportation (DOT) regulations are followed during shipment of these chemicals to minimize potential impacts to the public. During operation, the diesel generators used to power the treatment systems create the most noise and air emissions at the site. Because of the remoteness of the Leviathan Mine site, the public is not impacted by these issues. Alternative power sources are currently being evaluated, including wind and hydraulic turbines, which will replace or augment the diesel-powered generators.

3.10 Availability, Adaptability, and Transportability of Equipment

The components of both the active lime treatment system and semi-passive alkaline treatment lagoon are generally available and not proprietary. System process components include (1) reaction equipment such as pumps, pipes, and transfer lines; reaction, flocculation, and reagent tanks; mixers; and clarifiers; (2) control equipment such as pH monitoring systems, lime dosage and feed systems, polymer dosage and feed systems, mixer controls, and aeration controls; and (3) solids handling equipment such as filter presses, roll-off bins, and bag filters. This equipment is available from numerous suppliers throughout the country and may be ordered in multiple sizes to meet flow requirements and treatment area accessibility. An integrated design is recommended to properly size and assemble individual components for proper system operation.

Transport of reaction and reagent tanks, clarifiers, and filter presses to a site may require handling as oversize or wide loads. Additional consideration should be given to the stability of mine access roads, bridge clearances, and load limits for large shipments. Process reagents and consumables, such as lime and generator fuel, are considered hazardous materials and will require stable site access roads for delivery.

3.11 Ability to Attain ARARs

Under CERCLA, remedial actions conducted at Superfund sites must comply with Federal and state (if more stringent) environmental laws that are determined to be applicable or relevant and appropriate. Applicable or relevant and appropriate requirements (ARAR) are determined on a site-specific basis by the EPA remedial project manager. They are used as a tool to guide the remedial project manager toward the most environmentally safe way to manage remediation activities. The remedial project manager reviews each Federal environmental law and determines if it is applicable. If the law is not applicable, then the determination must be made whether the law is relevant and appropriate. Actions taken on-

site during a CERCLA cleanup action must comply only with the substantive portion of a given ARAR. On-site activities need not comply with administrative requirements such as obtaining a permit, record keeping, or reporting. Actions conducted off-site must comply with both the substantive and administrative requirements of applicable laws and regulations.

On-site remedial actions, such as the lime treatment systems in operation at the Leviathan Mine site, must comply with Federal and more stringent state ARARs, however, ARARs may be waived under six conditions: (1) the action is an interim measure, and the ARAR will be met at completion; (2) compliance with the ARAR would pose a greater risk to human health and the environment than noncompliance; (3) it is technically impracticable to meet the ARAR; (4) the standard of performance of an ARAR can be met by an equivalent method; (5) a state ARAR has not been consistently applied elsewhere; and (6) ARAR compliance would not provide a balance between the protection achieved at a particular site and demands on the Superfund for other sites. These waiver options apply only to Superfund actions taken on-site, and justification for the waiver must be clearly demonstrated.

The following sections discuss and analyze specific environmental regulations pertinent to operation of both lime treatment systems, including handling, transport, and disposal of both hazardous and non-hazardous treatment residuals. ARARs identified include: (1) CERCLA; (2) RCRA; (3) the Clean Air Act (CAA); (4) the Clean Water Act (CWA); (5) Safe Drinking Water Act (SDWA); and (6) Occupational Safety and Health Administration (OSHA) regulations. These six general ARARs, along with additional state and local regulatory requirements (which may be more stringent than Federal requirements) are discussed below. Specific ARARs that may be applicable to the both lime treatment systems are identified in Table 3-2.

3.11.1 Comprehensive Environmental Response, Compensation, and Liability Act

CERCLA of 1980 authorizes the Federal government to respond to releases or potential releases of any hazardous substance into the environment, as well as to releases of pollutants or contaminants that may present an imminent or significant danger to public health and welfare or to the environment. As part of the requirements of CERCLA, EPA has prepared the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) for hazardous substance response. The NCP, codified in Title 40 CFR Part 300, delineates methods and criteria used to determine the appropriate extent of removal and cleanup for hazardous waste contamination.

The 1986 SARA amendment to CERCLA directed EPA to:

- Use remedial alternatives that permanently and significantly reduce the volume, toxicity, or mobility of hazardous substances, pollutants, or contaminants.
- Select remedial actions that protect human health and the environment, are cost-effective, and involve permanent solutions and alternative treatment or resource recovery technologies to the maximum extent possible.
- Avoid off-site transport and disposal of untreated hazardous substances or contaminated materials when practicable treatment technologies exist (Section 121[b]).

In general, two types of responses are possible under CERCLA: removal and remedial actions. Removal actions are quick actions conducted in response to an immediate threat caused by release of a hazardous substance. Remedial actions involve the permanent reduction of toxicity, mobility, and volume of hazardous substances or pollutants. The lime treatment technologies implemented at the Leviathan Mine Superfund site fall under the purview of CERCLA and SARA; both lime treatment systems are operated on site and reduce the mobility of toxic metals through chemical precipitation and volume through metal concentration in filter cake and sludge. The technologies are protective of human health and the environment, cost effective, and permanent.

Both lime treatment technologies can be applied at sites such as Leviathan Mine and operated as long-term CERCLA remedial actions; however, they may also be designed and operated for short term operation at a site in support of a CERCLA removal action, where immediate removal of toxic metals from a waste stream is necessary.

3.11.2 Resource Conservation and Recovery Act

RCRA, an amendment to the Solid Waste Disposal Act, was enacted in 1976 to address the problem of safe disposal of the enormous volume of municipal and industrial solid waste generated annually. The Hazardous and Solid Waste Amendments of 1984, greatly expanded the scope and requirements of RCRA. Regulations in RCRA specifically address the identification and management of hazardous wastes. Subtitle C of RCRA contains requirements for generation, transport, treatment, storage, and disposal of hazardous waste, most of which are applicable to CERCLA actions. In order to generate and dispose of a hazardous waste, the site responsible party must obtain an EPA identification number. However, mining wastes are generally not subject to regulation under RCRA (see the Bevill Amendment at Section 3001(a)(3)(A)(ii)), unless the waste is disposed of off-site. For treatment residuals determined to be RCRA hazardous, substantive and administrative RCRA requirements must be addressed if the wastes are shipped off

Table 3-2. Federal Applicable or Relevant and Appropriate Requirements for both Lime Treatment Systems

	ARAR	Regulated Activity	Applicability
Characterization of untreated AMD and ARD	RCRA: 40 CFR Part 261 or state equivalent	Standards that apply to identification and characterization of wastes.	Not applicable as mine wastes are not subject to RCRA under the Bevill Amendment.
Construction of Treatment System	OSHA· 29 CFR 1910.120	Protection of workers from toxic metals during earth moving activities and system construction	Applicable. Provide air and noise monitoring and appropriate personnel protective equipment.
	CAA: 40 CFR Part 50 or state equivalent	Standards that apply to the emission of particulates and toxic pollutants.	Relevant and appropriate. Control emissions during earthwork using engineering controls. May require air monitoring and record keeping.
	CWA: 40 CFR Part 122	Standards for discharge of storm water generated during construction activities. Requires compliance with best management practices and discharge standards in nationwide storm water discharge permit for construction activities.	Not applicable to a CERCLA action; however, the substantive requirements are relevant and appropriate. Best management practices should be implemented to meet discharge standards.
Treatment System Operation	OSHA: 29 CFR 1910.120	Protection of workers from toxic metals during system operation and dust emissions during lime and treatment residual handling.	Applicable. Provide air appropriate personnel protective equipment.
	RCRA· 40 CFR Part 264 or state equivalent	Standards apply to treatment of wastes in a treatment facility.	Not applicable as mine wastes are not subject to RCRA under the Bevill Amendment. However, may be relevant and appropriate. Requires operational and contingency planning as well as record keeping.
	CAA: 40 CFR Part 50 or state equivalent	Standards that apply to the emission of particulates and toxic pollutants. .	Relevant and appropriate. Control emissions during lime transfer and treatment residual handling using engineering controls. May require air monitoring and record keeping.
Determination of Cleanup Standards	SARA: Section 121(d)(2)(A)(ii) SDWA: 40 CFR Part 141	Standards that apply to pollutants in waters that may be used as a source of drinking water.	Not applicable for removal actions. Effluent must meet interim discharge standards specified in the action memorandum. Applicable for remedial actions Effluent must obtain MCL and to the extent possible MCLGs.
Waste Disposal	RCRA: 40 CFR Part 261 or state equivalent	Standards that apply to identification and characterization of wastes.	Applicable only when treatment residuals are disposed of off-site May be relevant and appropriate for determination of waste type to guide selection of appropriate on-site disposal requirement.
	RCRA: 40 CFR Part 262 and 263	Standards that apply to generators of hazardous waste.	Applicable for off-site disposal of hazardous treatment residuals. Requires identification of the generator and disposal at a RCRA-permitted facility.
	CWA: 40 CFR Part 125	Standards for discharge of effluent to a navigable waterway. Requires a NPDES permit for discharge to a navigable waterway.	Not applicable to a CERCLA action; however, the substantive requirements are relevant and appropriate. Discharge standards may be more stringent than MCLs or MCLGs due to potential environmental impacts.

AMD = Acid mine drainage
ARAR = Applicable or relevant and appropriate requirement
ARD = Acid rock drainage
CAA = Clean Air Act
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act
CFR = Code of Federal Regulation
CWA = Clean Water Act
MCL = Maximum contaminant level
MCLG = Maximum contaminant level goal
NPDES = National Pollutant Discharge Elimination System
OSHA = Occupational Safety and Health Administration
RCRA = Resource Conservation and Recovery Act
SARA = Superfund Amendments and Reauthorization Act
SDWA = Safe Drinking Water Act

site for disposal. If treatment residuals remain on-site, the substantive requirements of state disposal and siting laws and the Toxic Pits Control Act may be relevant and appropriate. Criteria for identifying RCRA characteristic and listed hazardous wastes are included in 40 CFR Part 261 Subparts C and D. Other applicable RCRA requirements include hazardous waste manifesting for off-site disposal and time limits on accumulating wastes.

At Leviathan Mine, treatment residuals generated from the lime treatment systems include both RCRA hazardous and non-hazardous wastes. RCRA hazardous wastes are shipped off-site for disposal at a permitted TSD facility. Non-hazardous waste residuals are either stored or disposed of on site. Appropriate RCRA regulations are followed for generation, transport, treatment, storage, and disposal of the Leviathan Mine lime treatment residuals determined to be RCRA hazardous.

3.11.3 Clean Air Act

The CAA establishes national primary and secondary ambient air quality standards for sulfur oxides, particulate matter, carbon monoxide, ozone, nitrogen dioxide, and lead. It also limits the emission of 189 listed hazardous pollutants. States are responsible for enforcing the CAA. To assist in this, air quality control regions (ACQR) were established. Allowable emission limits are determined by the AQCR and AQMD subunits. The emission limits are established based on attainment of national ambient air quality standards.

The CAA requires that TSD facilities comply with primary and secondary ambient air quality standards. Emissions resulting from lime and solids handling during the operation of both lime treatment systems may need to meet air quality standards. For example, dust generated during lime and residual solids handling may be regulated by a local AQMD. No air permits are required for either lime treatment system operated at the Leviathan Mine Superfund site; however, dust emissions are limited through careful handling and maintaining soil moisture during operation.

3.11.4 Clean Water Act

The objective of the CWA is to restore and maintain the chemical, physical, and biological integrity of the nation's waters by establishing Federal, State, and local discharge standards. If treated water is discharged to surface water bodies or publicly-owned treatment works (POTW), CWA regulations will apply. A facility discharging water to a navigable waterway must apply for a permit under the NPDES. NPDES discharge permits are designed as enforcement tools with the ultimate goal of achieving ambient water quality standards. Discharges to POTWs also must comply with general pretreatment regulations outlined in 40 CFR Part 403, as well as other applicable state and local administrative and substantive requirements.

Treated effluent from both lime treatment systems is discharged to Leviathan Creek, if EPA discharge standards are met. An NPDES permit is not required under CERCLA, although the substantive requirements of the CWA are met.

3.11.5 Safe Drinking Water Act

The SDWA of 1974 and the Safe Drinking Water Amendments of 1986 require EPA to establish regulations to protect human health from contaminants in drinking water. The law authorizes national drinking water standards and a joint Federal-State system for ensuring compliance with these standards. The National Primary Drinking Water Standards are found at 40 CFR Parts 141 through 149. These standards are expressed as maximum contaminant levels (MCL) and maximum contaminant level goals (MCLG). Under CERCLA (Section 121(d)(2)(A)(ii)), remedial actions are required to meet MCLs and MCLGs when relevant and appropriate. State drinking water requirements may also be more stringent than Federal standards.

Effluent from both lime treatment systems discharges to Leviathan Creek, a potential source of drinking water. Effluent from the treatment systems meets the EPA discharge standards; however, aluminum concentrations do not meet the Federal MCL. Attainment of the MCL for aluminum is fully achievable through addition of more lime or increased HRT; however, under the current EPA action memorandum, operation of the Leviathan Mine lime treatment systems to meet MCLs is not required.

3.11.6 Occupational Safety and Health Act

CERCLA remedial actions and RCRA corrective actions must be conducted in accordance with OSHA requirements detailed in 29 CFR Parts 1900 through 1926, in particular Part 1910.120, which provides for health and safety of workers at hazardous waste sites. On-site construction at Superfund or RCRA corrective action sites must be conducted in accordance with 29 CFR Part 1926, which describes safety and health regulations for construction sites. State OSHA requirements, which may be significantly stricter than Federal standards, also must be met. Workers involved with the construction and operation of a lime treatment system are required to have completed an OSHA training course and be familiar with OSHA requirements relevant to hazardous waste sites. Workers on hazardous waste sites must also be enrolled in a medical monitoring program.

Minimum personal protective equipment (PPE) for workers at the Leviathan Mine site includes gloves, hard hat, steel-toe boots, and Tyvek® coveralls PPE, including respirators, eye protection, and skin protection is required when handling lime.

Based on contaminants and chemicals used at the site, the use of air purifying respirators or supplied air is not required. A man lift and personnel tie-off is suggested to reduce fall hazards when inspecting tanks, clarifiers, and elevated piping. Noise levels are generally not high, except during site preparation and solids handling, both of which involve the operation of heavy equipment. During these activities, noise levels are monitored to ensure that workers are not exposed to noise levels above a time-weighted average of 85 decibels over an eight-hour day. If noise levels exceed this limit, workers are required to wear hearing protection.

3.11.7 State Requirements

State and local regulatory agencies may require permits prior to operation of a lime treatment system. Most Federal permits will be issued by an authorized state agency. An air permit from the local AQMD may be required if air emissions in excess of regulatory standards are anticipated. State and local agencies will have direct regulatory responsibility for all environmental concerns. If a removal or remedial action occurs at a Superfund site, Federal agencies, primarily EPA, will provide regulatory oversight. If off-site disposal of contaminated waste is required, the waste must be taken to the disposal facility by a licensed transporter.

3.12 Technology Applicability to Other Sites

Lime treatment of AMD and ARD at Leviathan Mine was evaluated for applicability to other mine sites based on the nine criteria used for decision making in the Superfund feasibility study process. The nine criteria and the results of the evaluation are summarized in Table 3-3. The active and semi-passive lime treatment systems evaluated were specifically designed to treat AMD and ARD at the mine site to EPA discharge standards for aluminum, arsenic, copper, iron, and nickel. In addition to the five primary target metals of concern, EPA identified cadmium, chromium, lead, selenium, and zinc as secondary water quality indicator metals. The lime treatment systems implemented at Leviathan Mine were also successful at reducing concentrations of these secondary metals in the AMD and ARD to below EPA discharge standards. Either treatment system can be modified to treat wastes with varying metals concentrations and acidity.

Table 3-3. Feasibility Study Criteria Evaluation for Both Lime Treatment Systems at Leviathan Mine

Criteria	Technology Performance
Overall Protection of Human Health and the Environment	Lime treatment has been proven to be extremely effective at reducing concentrations of aluminum, arsenic, copper, iron, nickel, and other dissolved metals in AMD and ARD. The lime treatment systems evaluated at Leviathan Mine reduced the concentrations of toxic metals in AMD and ARD, which was historically released to Leviathan Creek, to below EPA discharge standards, which were established to protect water quality and the ecosystem in Leviathan Creek and down-stream receiving waters. Resulting metals-laden solid wastes, that are determined to be hazardous based on State or Federal criteria, are transported to an approved off site TSD facility for proper disposal, again protecting human health and the environment from these hazardous materials.
Compliance with Applicable or Relevant and Appropriate Requirements (ARAR)	Both lime treatment systems are compliant with EPA discharge standards for the Leviathan Mine site. However, the effluent from the treatment systems does not meet the primary maximum contaminant limit (MCL) for aluminum or the secondary MCL for iron, which could easily be met with additional lime dosing Hazardous process residuals must be handled in accordance with Resource Conservation and Recovery Act and/or state of California hazardous materials transportation and disposal regulations
Long-term Effectiveness and Performance	The active lime treatment system has been in operation at Leviathan Mine since 1999, and the semi-passive alkaline lagoon since 2001. After implementation of the active lime treatment system in 1999, no overflows of metals-laden AMD have occurred from the mine site. The treatment systems continue to be operated by the state of California and ARCO Long-term optimization of the lime treatment system will likely reduce maintenance issues related to gypsum precipitation and lime feed problems in the process equipment, which are the major performance issues for the systems. Neither system is operational during the winter months due to freezing conditions and limited site access. During winter shutdown, ARD is discharged to Leviathan Creek, while AMD is captured and stored in the on site retention ponds. Return of ARD to the creek limits long term effectiveness of the treatment process; however, this will be addressed by capturing the ARD flow and redirecting it to the storage ponds during the winter months, or to an active lime treatment system housed in a heated structure.
Reduction of Toxicity, Mobility, or Volume through Treatment	Lime treatment significantly reduces the mobility and volume of toxic metals from AMD and ARD at Leviathan Mine. The dissolved toxic metals are precipitated from solution, concentrated, and dewatered removing toxic levels of metals from the AMD and ARD However, lime treatment does produce a significant quantity of solid waste. Solid wastes generated from the lime treatment systems that are determined to be non-hazardous are disposed of on site Solid wastes that exceed State or Federal hazardous waste criteria are transported to an approved off site TSD facility for proper disposal
Short-term Effectiveness	The resulting effluent from the lime treatment systems does not pose a risk to human health. The hydrated lime solution and the metal hydroxide precipitates, each having hazardous chemical properties, may pose a risk to site workers during treatment system operation. Exposure to these hazardous chemicals must be mitigated through engineering controls and proper health and safety protocols.
Implementability	The lime treatment technology relies on a relatively simple chemical process and can be constructed using readily available equipment and materials. The technology is not proprietary, nor does it require proprietary equipment or reagents Once installed, the systems can be optimized and maintained indefinitely. Winter shut downs and startups and routine maintenance all require significant time and manpower. The remoteness of the site also necessitates organized, advanced planning for manpower, consumables, and replacement equipment and supplies.
Cost	Total first year cost for the construction and operation of the active lime treatment system operated in biphasic mode was $1.48M and 1.22M operated in monophasic mode. Total first year cost to construct and operate the semi-passive alkaline lagoon was $0.81M. The operation and maintenance costs associated with the treatment systems are: $16.97 per 1,000 liters at an AMD flow rate of 638.7 liters per minute (L/min) for the active lime treatment system operated in biphasic mode; $20.97 per 1,000 liters at a combined AMD/ARD flow rate of 222.6 L/min for the system operated in monophasic mode, and $16.44 per 1,000 liters at an ARD flow rate of 78.7 L/min for the semi-passive alkaline lagoon treatment system. Costs provided for each treatment system are dependent on local material, equipment, consumable, and labor costs, required discharge standards, and solid waste classification and disposal requirements.
Community Acceptance	The lime treatment technology presents minimal to no risk to the public since all system components are located at and treatment occurs on the Leviathan Mine site, which is a remote, secluded site. Hazardous chemicals used in the treatment system include lime and diesel fuel These chemicals pose the highest risk to the public during transportation to the site by truck. The diesel generators create the most noise and air emissions at the site, again, because of the remoteness of the site, the public is not impacted.
State Acceptance	The state of California selected and is currently operating the active lime treatment system in biphasic mode, which indicates the State's acceptance of the technology to treat AMD. Furthermore, the state of California concurs with the treatment of ARD by ARCO using the semi-passive alkaline lagoon treatment system. However, the state of California has expressed concern about the return of ARD to Leviathan Creek during the winter months. Capture and on site storage of ARD over the winter months or year-round treatment would alleviate State concerns and is currently being evaluated by ARCO.

AMD = Acid mine drainage
ARCO = Atlantic Richfield Company
ARD = Acid rock drainage
EPA = U.S. Environmental Protection Agency
TSD = Treatment, storage, and disposal

SECTION 4
ECONOMIC ANALYSIS

This section presents an economic analysis of the active lime treatment and semi-passive alkaline lagoon treatment systems used to treat AMD and ARD with chemistry, flow rates, and site logistical issues similar to those at the Leviathan Mine.

4.1 Introduction

The information presented in this section has been derived from (1) observations made and experiences gained during each technology evaluation, (2) data compiled from the Leviathan Mine Site Engineering Evaluation/Cost Analysis (EE/CA) (EMC^2 2004a), and (3) personal communication with EMC^2 (EMC^2 2004b). The costs associated with designing, constructing, and operating the two lime treatment systems have been broken down into the following 11 elements and are assumed to be appropriate for extrapolation to other mine sites with similar conditions. Each cost element is further broken down to document specific costs associated with each treatment system.

1) Site Preparation
2) Permitting and Regulatory Requirements
3) Capital Equipment
4) System Startup and Shakedown
5) Consumables and Rentals
6) Labor
7) Utilities
8) Residual Waste Shipping, Handling and Disposal
9) Analytical Services
10) Maintenance and Modifications
11) Demobilization

This economic analysis is based primarily on data collected during the 2003 evaluation period for the active lime treatment system and the 2002 evaluation period for the semi-passive alkaline lagoon treatment system. During the 2003 evaluation period the active lime treatment system operated in monophasic mode for four weeks (June 18 to July 20, 2003) and treated 9,538,200 liters of a blend of AMD and ARD (adit, PUD, CUD, and Delta Seep) at an average rate of 222.6 L/min. The active lime treatment system also operated in biphasic mode for approximately two weeks in 2003 (July 28 to August 14, 2003), treating 13,247,500 liters of AMD from the retention ponds at an average rate of 638.7 L/min. The semi-passive alkaline lagoon treatment system operated for 16 weeks in 2002 (June 26 to October 31, 2002), treating 11,998,450 liters of ARD from the CUD at an average rate of 78.7 L/min. Costs are presented for each system for their respective period of operation. The cost per 1,000 liters of water treated is presented as well as the present worth of the cumulative variable costs over 5, 10, and 15 years of treatment. Comparison of treatment costs between systems is problematic because of different source waters and flow rates. In addition, influent metals load and acidity varies significantly between sources.

Section 4.2 presents a cost summary and identifies the major expenditures for each treatment system (costs are presented in 2003 dollars). As with any cost analysis, caveats may be applied to specific cost values based on associated factors, issues and assumptions. The major factors that can affect estimated costs are discussed in Section 4.3. Assumptions used in the development of this economic analysis are identified in Section 4.4. Detailed analysis of each of the 11 individual cost elements for both treatment systems is presented in Section 4.5.

4.2 Cost Summary

The initial fixed costs to construct the lime treatment systems are (1) $1,021,415 for the active lime treatment system operated in monophasic mode, (2) $1,261,076 for the active lime treatment system operated in biphasic mode, and (3) $297,482 for the semi-passive alkaline lagoon treatment system. Fixed costs consist of site preparation, permitting, and capital and equipment costs. Site preparation includes system design, project management, and construction management. Capital and equipment costs include all equipment, materials, delivery, and initial system construction. Equipment and materials include reaction tanks, settling tanks, piping, pumps, valves, pH control equipment, automation equipment and satellite phone for reliable communication at a

remote site. A breakdown of fixed costs for each system is presented in Section 4.5.

Variable costs to operate the active lime treatment system are $200,022 in monophasic mode and $224,813 in biphasic mode. The variable costs for the semi-passive alkaline lagoon treatment system are $195,151. Variable costs consist of system startup and shakedown, consumable and rentals, labor, utilities, waste handling and disposal, analytical services, maintenance and system modifications, and system winterization. A breakdown of variable costs for each system is presented in Section 4.5.

The total first year cost to design, construct, and operate each treatment system; yearly operational costs for each treatment system; and the cumulative 5-year, 10-year, and 15-year treatment costs for each treatment system are summarized in Table 4-1.

4.3 Factors Affecting Cost Elements

A number of factors can affect the cost of treating AMD and ARD with either the active or semi-passive lime treatment systems. These factors generally include flow rate, concentration of contaminants, discharge standards, physical site conditions, geographical site location, and type and quantity of residuals generated. Increases in flow rate due to seasonal changes may raise operating costs of each system due to proportional increases in lime and polymer consumption. Flow rate increases can also impact fixed costs (number and size of reaction and settling tanks) when the minimum system or unit operation HRT is not sufficient to meet discharge standards. Operating costs are slightly impacted by increases in contaminant concentration, which may occur through evaporative reduction during the summer months. Increases in metals concentrations generally require additional lime dosing to attain discharge standards. Higher contaminant concentrations may also change the classification of a residual waste from a non-hazardous to a hazardous waste, requiring increased disposal costs. Restrictive discharge standards impact both fixed and variable costs. System designers and operators may be forced to extend system and unit operation HRTs (number and size of reaction and settling tanks) and increase lime dosage to meet stricter discharge requirements. Physical site conditions may impact site preparation and construction costs associated with excavation and grading of the treatment area and associated AMD retention and solids settling ponds. Cold climates may limit site access and shorten the treatment season due to freezing of piping, requiring AMD retention ponds and systems designed to operate at a high treatment rate during a shorter treatment season. The characteristics of the residual solids produced during treatment may greatly affect disposal costs, where production of hazardous solids will require off site disposal at a permitted TSD facility.

4.4 Issues and Assumptions

The following assumptions have been used in the development of this economic analysis:

- AMD collection ponds have been previously constructed and do not require maintenance.
- Solids settling ponds have been previously constructed and do not require maintenance.
- Standard sized tanks are used as reactors and mixing tanks.
- An appropriate staging area is available for equipment staging, setup and delivery.
- Water treatment will occur only when the site is accessible.
- Construction and maintenance of access roads is no required.
- Each system will be operated continuously during the treatment period.
- Each system will be operated unmanned during the night, but will not discharge without personnel on site.
- All site power is obtained from on site diesel generators.
- Utility water can be obtained on site.

Table 4-1. Summary of Total and Variable Costs for Each Treatment System

Description	Active Lime Treatment System Monophasic Operation	Active Lime Treatment System Biphasic Operation	Semi-Passive Alkaline Lagoon Treatment System
Total First Year Cost	$1,221,437	$1,478,842	$474,428
First Year Cost per 1,000 Liters Treated	$128.05	$111.63	$39.54
Total Variable Costs	$200,022	$224,814	$197,200
Variable Costs per 1,000 Liters Treated	$20.97	$16 97	$16 44
Cumulative 5-Year Total Variable Cost (Present Worth at 7 Percent Rate of Return)	$820,129	$921,780	$808,559
Cumulative 10-Year Total Variable Cost (Present Worth at 7 Percent Rate of Return)	$1,404,871	$1,578,998	$1,385,051
Cumulative 15-Year Total Variable Cost (Present Worth at 7 Percent Rate of Return)	$1,821,783	$2,047,585	$1,796,081

- Hazardous sludge will be disposed of at an off site TSD facility.
- The site is located within 400 kilometers of the off-site TSD facility.
- Non-hazardous sludge can be disposed of on site.
- Permitting for the treatment systems is not required because of CERCLA status.
- Treatment goals and discharge standards apply to those presented in Table 2-5.
- Samples are collected and analyzed daily during discharge to verify attainment of discharge standards.

4.5 Cost Elements

Each of the 11 cost elements identified in Section 4.1 has been defined and the associated costs for each treatment system element presented below. The cost elements for the active lime treatment system are summarized in Table 4-2, and in Table 4-3 for the semi-active alkaline treatment lagoon. Cost element details for each treatment system are presented in Appendix C.

4.5.1 Site Preparation

Site preparation for each treatment system addresses only system design, construction management and project management. AMD retention and solids settling ponds and a cleared and graded treatment area were already in place; therefore costs for these activities are not provided in this analysis. However, for other sites, site preparation may require clearing vegetation, construction of AMD retention and solids settling ponds, and grading of an area for the treatment system.

Active Lime Treatment System. System design is estimated at 20 percent of the capital and equipment cost for the active lime treatment system. Construction management is estimated at 15 percent and project management at 10 percent of the capital and equipment costs for the system (US Army Corp of Engineers [USACE] 2000). The total site preparation cost for the active lime treatment system operated in monophasic mode is $316,991; the total site preparation cost for the active lime treatment system operated in biphasic mode is $389,181.

Semi-Passive Alkaline Treatment Lagoon. The total site preparation cost for the alkaline lagoon treatment system is $88,812. Design, construction management, and project management costs were estimated at 20 percent, 15 percent, and 10 percent of the capital and equipment costs, respectively. The semi-passive alkaline lagoon treatment system did require minor berm extension and site grading as well as pond liner installation; however, these costs are included as general site work items in the capital and equipment portion of this analysis rather than under site preparation.

4.5.2 Permitting and Regulatory Requirements

Permitting and regulatory costs vary depending on whether treatment occurs at a CERCLA-lead or a state- or local authority-lead site. At CERCLA sites such as Leviathan Mine, removal and remedial actions must be consistent with environmental laws, ordinances, and regulations, including Federal, State, and local standards and criteria; however, permitting is not required.

At a state- or local authority-lead site, a NPDES permit, an air permit, and a storm water permit will likely be required as well as additional monitoring, which can increase permitting and regulatory costs. National Environmental Policy Act or state equivalent documentation may also be required for system construction. For a treatment system similar to those described here, constructed at a state- or local authority-lead site, permitting and regulatory costs are estimated to be $50,000.

4.5.3 Capital Equipment

Capital costs include delivery and installation of system equipment and assembly of system components. Equipment includes reaction, settling, and storage tanks; pumps, piping, and valves; pH control equipment; and automation equipment. This analysis assumes that an area of at least 4,050 to 6,070 square meters is available for installation of equipment, system assembly, and staging supplies. The cost for excavation or grading of such a staging area is not included in this economic analysis.

Active Lime Treatment System. Total capital expenditure for the active lime treatment system is $704,424 for the monophasic system and $864,847 for the biphasic system. The cost for installation of the active lime treatment system is approximately $668,353 for the monophasic system and $817,486 for the biphasic system. The cost to route AMD and ARD from four different sources (CUD, Delta Seep, Adit, and PUD) to the treatment system operated in monophasic mode is $16,592. The CUD and Delta Seep require capture, pumping, and routing of ARD approximately 500 meters to the treatment system. Routing of Adit/PUD flows approximately 150 meters to the system does not require pumping. For biphasic operations, AMD is pumped directly from the retention pond adjacent to the treatment system at a cost of $930. An additional cost of $26,952 is incurred for pumping solids slurry from the Phase II clarifier to the pit clarifier for settling. Automation components of the system include an automatic pH control system and a remote monitoring/alarm system at a cost of approximately $17,985, including installation. A satellite phone to provide reliable communication at a remote location is estimated at $1,495.

Table 4-2. Summary of Cost Elements for the Active Lime Treatment System

Description	Monophasic Subtotal	Biphasic Subtotal
Site Preparation	**$316,990.86**	**$389,181.24**
Permitting and Regulatory	**$0.00**	**$0.00**
Capital and Equipment	**$704,424.14**	**$864,847.22**
Conventional Lime Treatment System	**$668,352.64**	**$817,485.72**
Phase I Reaction Module	$93,361 44	$93,361.44
Phase I Clarifier Module	$0 00	$149,133.08
Phase I Solids Separation	$0.00	$116,662 36
Phase II Reaction Module	$102,611.28	$102,611.28
Phase II Clarifier Module	$125,267.24	$125,267.24
Phase II Solids Separation	$116,662.36	$0.00
Lime Slurry Equipment	$19,394 04	$19,394 04
Utility Water Delivery/Storage	$87,966.28	$87,966.28
Fuel Storage	$6,150.00	$6,150.00
System Assembly	$116,940 00	$116,940.00
Collection Pumping and Appurtenances	**$16,592.00**	**$27,882.00**
Capture and Route Delta Seep Flows to Channel Under Drain	$6,214.00	$0.00
Route Delta Seep and Channel Under Drain to System	$9,448.00	$0.00
Route Adit/ Pit Under Drain Flows to System	$930.00	$930.00
Route Phase II Clarifier Slurry to Pit Clarifier	$0.00	$26,952.00
Automation	**$17,984.50**	**$17,984.50**
Remote Monitoring/ Alarm System	$9,742.50	$9,742.50
pH Controller System	$8,242.00	$8,242.00
Communications	**$1,495.00**	**$1,495.00**
Total Fixed Cost	**$1,021,415.00**	**$1,254,028.46**
System Start-up and Shakedown	**$17,980.80**	**$22,400.00**
Consumables and Rentals	**$41,993.12**	**$55,609.80**
Labor	**$73,699.12**	**$66,760.00**
Utilities	**$20,982.00**	**$17,388.80**
Residual Waste Handling and Disposal	**$16,306.00**	**$20,175.00**
Analytical Services	**$3,080.00**	**$2,080.00**
Maintenance and Modifications	**$8,000.00**	**$18,000.00**
Demobilization	**$17,980.80**	**$22,400.00**
Total Variable Cost	**$200,021.84**	**$224,813.60**
Total 1st Year Cost	**$1,221,436.84**	**$1,478,842.06**
Total 1st Year Cost/1,000-Liters	**$128.05**	**$111.63**
Total Variable Cost/1,000-Liters	**$20.97**	**$16.97**
Cumulative 5-Year Total Variable Cost (Present Worth at 7 Percent Rate of Return)	**$820,129.00**	**$921,780.00**
Cumulative 10-Year Total Variable Cost (Present Worth at 7 Percent Rate of Return)	**$1,404,871.00**	**$1,578,998.00**
Cumulative 15-Year Total Variable Cost (Present Worth at 7 Percent Rate of Return)	**$1,821,783.00**	**$2,047,585.00**

Table 4-3. Summary of Cost Elements for the Semi-passive Alkaline Lagoon Treatment System

Description	Subtotal
Site Preparation	**$88,812.03**
Permitting and Regulatory Costs	**$0.00**
Capital and Equipment	**$188,415.25**
General Site Work	$98,572.51
Collection Systems	$30,776.23
Equipment	$33,896.34
Electrical	$3,384.30
Miscellaneous	$21,785.87
Total Fixed Cost	**$277,227.28**
System Start up and Shakedown	**$11,612.16**
Consumables and Rentals	**$41,715.52**
Labor	**$92,572.76**
Utilities	**$15,922.66**
Residual Waste Handling and Disposal	**$17,325.00**
Analytical Services	**$1,040.00**
Maintenance and Modifications	**$5,400.00**
Demobilization	**$11,612.16**
Total Variable Cost	**$197,200.26**
Total 1st Year Cost	**$474,427.54**
Total 1st Year Cost/1,000-Liters	**$39.54**
Total Variable Cost/1,000-Liters	**$16.44**
Cumulative 5-Year Total Variable Cost (Present Worth at 7 Percent Rate of Return)	**$808,559.00**
Cumulative 10-Year Total Variable Cost (Present Worth at 7 Percent Rate of Return)	**$1,385,051.00**
Cumulative 15-Year Total Variable Cost (Present Worth at 7 Percent Rate of Return)	**$1,796,081.00**

Semi-Passive Alkaline Lagoon Treatment System. Total capital expenditures for the semi-passive alkaline lagoon treatment system are approximately $188,415. These costs have been broken down into general site work, collection systems, equipment, electrical, and miscellaneous costs. General site work ($98,573) makes up nearly one-half of the total capital and equipment cost and includes general site grading, lining of the alkaline lagoon, extending the northern lagoon berm to increase space for reaction tanks and bag filters, and installing silt curtains within the lagoon. Approximately 16 percent of the capital costs ($30,776) consist of the collection systems used to route CUD flow to the treatment system. Approximately 18 percent of the capital costs ($33,896) consist of the reaction and storage tanks, pumps, compressors, and aerators used in system construction. The remainder of the capital costs ($25,170) consists of electrical equipment, monitoring equipment, and storage bins. All alkaline lagoon treatment system capital costs are loaded to account for system assembly. The total capital cost for the semi-passive alkaline lagoon treatment system is approximately one-quarter the cost of the active lime treatment system.

4.5.4 *Startup and Fixed Costs*

System start-up and shakedown includes the labor to setup pumps, pipes, and rental equipment, test system hydraulics, startup the system, and optimize the system to meet discharge standards. System startup and shakedown occurs at the beginning of each treatment season as the system is cleaned and disassembled each winter. After system assembly and start up, a shake down is necessary to ensure that any problems are identified and addressed prior to optimization. The system is then optimized for the desired source water, flow rate, and discharge standards. This process generally requires 1.5 to 2 weeks of labor for a field crew of four who are familiar with the system. Additional time required for additional optimization has been built into system assembly costs.

Active Lime Treatment System. The estimated start up cost for the active lime treatment system is $17,981 for operation in monophasic mode and $22,400 for operation in biphasic mode. It is assumed that assembly and shake down of either system will take a four-person crew 10 8-hour work days to complete. The cost difference between the two modes of operation is due to the different documented labor rates for system operators.

Semi-Passive Alkaline Treatment Lagoon. The estimated start up cost for the alkaline lagoon treatment system is $11,612. It is assumed that assembly and shake down of the semi-passive alkaline treatment lagoon system will take a four-person crew eight 8-hour working days to complete. Startup and shakedown costs for this system are less than the active lime treatment system due to the simplicity of system design.

4.5.5 *Consumables and Supplies*

Consumables and rentals for each system consist of chemicals and supplies required to treat AMD and ARD, including lime, polymer, bag filters, health and safety equipment, field trailer rental, storage connex rental, compressor rental, and heavy equipment rental. It is assumed that field trailers, compressors and heavy equipment will be used from the time system assembly begins until winterization is complete. Storage connexes will be rented year round.

Active Lime Treatment System. Total consumable and rental costs for the active lime treatment system are $41,993 for monophasic operation and $55,610 for biphasic operation. The largest consumable expenditure is lime. Lime was consumed at a rate of approximately 1.294 grams of dry lime per liter of AMD and ARD treated during monophasic operation, at a cost of $4,978. Under biphasic operation, 3.397 grams of dry lime was consumed per liter of AMD treated at a cost of $16,864. The largest rental cost is for equipment storage from year to year. It is assumed that five storage connexes will be necessary for this system, operated in either mode. Storage connexes for either mode cost $19,500 per year, regardless of the duration of the treatment season. One field trailer is used from the time of system mobilization until winterization is completed. A mobilization and set-up fee is included for each field trailer and connex.

Semi-Passive Alkaline Treatment Lagoon System. Total consumable and rental costs for the semi-passive alkaline treatment lagoon are $41,716. The largest consumable expenditure is lime. Lime was consumed at a rate of approximately 1.467 grams of dry lime per liter of ARD treated, at a cost of $7,100. The largest rental cost is for equipment storage year to year. Three storage connexes were necessary for this system. Storage connexes cost $11,700 per year, regardless of the duration of the treatment season. One field trailer is used from the time of system mobilization until winterization is completed. A mobilization and set-up fee is included for each field trailer and connex.

4.5.6 *Labor*

Labor costs for each system include the field personnel necessary to operate the system and to address day-to-day maintenance issues. Labor associated with system startup and shakedown and system winterization is included in Sections 4.5.4 and 4.5.11, respectively. In addition to the full-time field crew, approximately one-half of the labor cost is dedicated to project and program management, engineering, and administrative support.

Active Lime Treatment System. Field personnel are necessary to operate the system, address day-to-day maintenance issues, drop solid wastes from the filter press, collect discharge monitoring samples, monitor unit operation pH and flow rates, and to adjust lime and polymer dosage rates. Field technicians accounted for $39,052 out of the total labor expenditure of $73,699 for monophasic operations. Field technicians accounted for $32,900 out of the total labor expenditure of $66,760 for biphasic operations.

Semi-Passive Alkaline Lagoon Treatment System. Labor costs for the semi-passive alkaline lagoon treatment system include system operation, addressing day-to-day maintenance issues, collecting discharge monitoring samples, monitoring unit operation pH and flow rates, adjusting lime dosage and aeration rates, and discharging treated water. Due to the more passive nature of the alkaline lagoon treatment system, less operating and maintenance labor is necessary in comparison to the active lime treatment system. Field technician labor accounted for $58,061 out of the total labor expenditure of $92,573 during the evaluation period. Total field technician labor exceeded that for the active lime treatment system due to the longer period of operation.

4.5.7 *Utilities*

Due to the remote nature of the site, utilities are not available. Utility costs generally consist of the cost to lease generators, generator fuel, portable toilet rental, and satellite phone service. Water is gravity fed to the treatment system from Leviathan Creek. Supervisory Control and Data Acquisition (SCADA) service through a satellite uplink has also been included for the active lime treatment system.

Active Lime Treatment System. Generator rental for the active lime treatment system includes one primary 125 kW generator and one backup 125 kW generator. Utilities are generally necessary from system assembly until system winterization is complete. Utility costs to support operation of the system in are $20,982 for operation in monophasic mode and $17,389 for operation in biphasic mode.

Semi-Passive Alkaline Lagoon Treatment System. Generator rental for the treatment system includes one primary 40 kW generator and one backup 25 kW generator. Utilities are generally necessary from system assembly until system winterization is complete. Total utility costs to support operation of the system are $15,923. Utility costs for the system are lower than the active lime treatment system due to the smaller number and size of pumps and mixers as well as a lower flow rates.

4.5.8 *Residual Waste Shipping, Handling, and Disposal*

The lime treatment process produces a large quantity of metal hydroxide sludge and filter cake. Solid waste residuals produced by the treatment systems were evaluated for hazardous waste characteristics. Solid waste residuals that were determined to be hazardous were transported to an off-site TSD facility for disposal; while non-hazardous solids were disposed of on-site or shipped to a non-hazardous waste repository.

Active Lime Treatment System. The filter cake produced during the active lime treatment process generally contains levels of arsenic exceeding State hazardous waste criteria. The active lime treatment system operated in monophasic mode generated 15.2 dry tons of hazardous filter cake, while biphasic operations generated 21.1 dry tons of hazardous filter cake and 93.6 dry tons of pit clarifier solids. The cost to remove this hazardous waste to an off-site TSD facility is approximately $16,306 for monophasic filter cake and $10,275 for biphasic filter cake. Non-hazardous waste from the biphasic mode must be removed from the pit clarifier approximately every third year and disposed of in an on site storage pit. The cost to dispose of the dewatered non-hazardous sludge is approximately $30,000 per event. This cost is divided evenly between each year for this analysis and assumed to be $9,900 for the evaluation period.

Semi-Passive Alkaline Lagoon Treatment System. The semi-passive alkaline lagoon treatment system generated 22.1 dry tons of non-hazardous bag filter and lagoon solids. Removal of solids from the bag filters is performed at the end of each treatment season; the solids disposed of off-site in a non-hazardous waste repository at a total cost of $17,325. Solids accumulation in the treatment lagoon occurs at a slow enough rate to require removal once every five years. Excavation and disposal of lagoon solids has not yet occurred, therefore no associated cost has been included in this analysis.

4.5.9 *Analytical Services*

Analytical costs associated with each lime treatment system consist of daily sampling to verify compliance with discharge standards. One effluent grab sample is collected each day during continuous discharge or prior to batch discharge and analyzed for metals using EPA Methods 6010B and 7470 to demonstrate compliance with discharge standards. A grab sample of each solid waste stream is also collected to support waste characterization and disposal. Each grab solid sample is analyzed for metals using EPA Methods 6010B and 7471 and leachable metals using the EPA Methods 1311, 6010B, and 7470 for comparison to Federal RCRA and TCLP criteria and California DI WET/EPA Method 6010B for comparison to State TTLC and STLC criteria.

Active Lime Treatment System. The cost for daily analytical services is $2,800 for the active lime treatment system operated in monophasic mode and $1,520 for biphasic operations. Analysis of one filter cake sample generated during monophasic operations is required at a cost of $280; while analysis of a filter cake and pit clarifier sludge sample generated during biphasic operations is required at a cost of $560. Solids samples are collected at the end of the treatment season to support waste characterization and disposal.

Semi-Passive Alkaline Lagoon Treatment System. The semi-passive alkaline lagoon treatment system discharges in batches approximately every 18 days. Six effluent grab samples were analyzed during the evaluation period at a total cost of $1,040. Analysis of bag filter and lagoon solids samples, at a cost of $560, is required to support waste characterization and disposal at the end of the treatment season.

4.5.10 *Maintenance and Modifications*

Maintenance and modifications costs include regular equipment replacement due to wear and tear. Equipment expected to require replacement includes plugged lime and polymer delivery lines, piping, pumps, mixers and filter press plates.

Active Lime Treatment System. The annual equipment replacement cost for the active lime treatment system operated in monophasic and biphasic modes is approximately $8,000 and $18,000, respectively. Equipment expected to be replaced each treatment season includes: sludge pumps and piping, aerators, pH probes, and lime and polymer delivery tubing. Peristaltic pumps, filter press plates, clarifier plates, mixers and water delivery pumps are expected to be replaced approximately every five years.

Semi-Passive Alkaline Lagoon Treatment System. The annual equipment replacement cost for the alkaline lagoon treatment system is approximately $5,400. The lime recirculation pumps, lime delivery tubing, and pH probes are expected to be replaced each treatment season. Water delivery pumps, mixers and trash pumps are expected to be replaced approximately every five years.

4.5.11 Demobilization

Demobilization includes labor to clean, disassemble, and store system components at the end of each treatment season. Demobilization activities include draining unused reagents from the system, cleaning the interior of reaction tanks, lime slurry tanks, and clarifiers; disassembly, cleaning, and storage of pumps and piping; returning of rental equipment; and consolidation and off-site disposal of hazardous waste.

Active Lime Treatment System. The estimated cost for demobilization of the active lime treatment is $17,981 for monophasic operations, and $22,400 for biphasic operations. It is assumed that demobilization of either mode of operation will require ten 8-hour work days for a four-person crew to complete. The cost difference is due to the different documented labor rates for the system operators.

Semi-Passive Alkaline Treatment Lagoon. The estimated cost for demobilization of the alkaline lagoon treatment system is $11,612. It is assumed that demobilization of the system will require eight 8-hour work days for a four-person crew to complete. Demobilization costs for this system are less than the active lime treatment system due to the simplicity of system design and fewer overall components.

SECTION 5
DATA QUALITY REVIEW

The analytical data collected during the SITE demonstration were collected in accordance with the 2002 and 2003 TEP/QAPPs (Tetra Tech 2002 and 2003). As part of the quality assurance/quality control (QA/QC) requirements specified in the TEP/QAPPs, any deviations from the sampling plans, such as missed sampling events, changes in sampling locations, or changes in analytical methods, were documented throughout the duration of the demonstration and are presented in Section 5.1. Documentation of these deviations is important because of the potential effects they have on data quality and on the ability of the data to meet the project objectives.

As part of the QA/QC data review, sample delivery groups (SDG) received from the laboratory underwent data validation through a third-party validator to ensure that the data generated is of a quality sufficient to meet project objectives. As specified in the TEP/QAPPs, data packages underwent 10 percent full validation in accordance with EPA validation guidance (EPA 1995). A Summary of the data validation performed on the lime treatment technology SITE demonstration data is presented in Section 5.2.

5.1 Deviations from TEP/QAPP

Due to various operating issues, several changes were required in the operation and sampling of the lime treatment systems during the SITE demonstration. One deviation from the TEP/QAPP that affected the sampling design for both treatment systems affected the ability to conduct the four-consecutive-day sampling events. Although initially planned so that discharge data could be compared to EPA's 4-day average discharge standard, these consecutive day sampling events were not conducted. As an alternative, the SITE demonstration team determined that comparing the average concentration from four consecutive sampling events would be sufficient to complete the effluent discharge comparisons against the four-day discharge standards. Deviations from the TEP/QAPPs related to the operation of each treatment system were documented throughout the duration of the SITE demonstration and are presented below.

Active Lime Treatment System

- The daily order of sample collection was modified due to system upsets and the need to sample the system at equilibrium. Detailed internal sample collection was also postponed until later in the sampling season to ensure that the pit clarifier was equilibrated.
- Samples were not collected at the AMD influent box due to lack of accessibility, instead a sampling port was installed in the system influent pipe.
- Samples were not collected from three locations due to changes in system operation. Phase II clarifier overflow (S6) has been discontinued; instead the solids slurry is discharged to the pit clarifier. Sample location S9 (pit clarifier effluent) is now equivalent to sample location S2 (system effluent), as pH adjustment no longer occurs at the effluent box above location S2. Sample location S10 (the first Phase I solids holding tank overflow) is no longer present, instead sample location S11 (the second Phase I solids holding tank overflow) combines the overflow from both tanks.
- Analyzed an effluent split sample collected by RWQCB to verify their laboratory findings.
- Analyzed 2002 monophasic trial samples collected by RWQCB at the treatment system influent and Phase I Clarifier effluent locations. Submitted both filtered and unfiltered grab samples for analysis.
- Collected an unsettled solids slurry sample at the pit clarifier influent (S7) for a field solids settling test.
- Collected samples at pit clarifier effluent (S2), Phase II clarifier influent (S5), and pit clarifier influent (S7) for total solids and TSS analyses. Data will be used in conjunction with field solids settling test results to assess clarifier efficiency.
- Collected a field blank and equipment rinsate sample to assess the source of trace levels of mercury showing up in the analytical data.

- Collected pit clarifier sludge (S7), monophasic trial sludge (S2), and filter cake (S13) solids samples at the direction of the EPA task order manager (TOM) to assess the content and leachability of metals in the treatment system waste streams. The solids samples were analyzed for total metals and metals after TCLP extraction, SPLP extraction, and California DI WET extraction. The solids samples were also analyzed for total solids and percent moisture in order to estimate the likely increase in metals concentration after drying.

Alkaline Treatment Lagoon

- Detailed internal sample collection was postponed until later in the sampling season to ensure that the lagoon had equilibrated.
- Samples were not collected at S7 (Cell 3) due to changes in system operation. System effluent no longer discharges through the snorkel in the lagoon, instead the system effluent is periodically pumped out of Cell 3. Therefore, the system effluent sampling location (S2) was moved to Cell 3.
- Sample collection at locations S11a (bag filter influent) and S11b (bag filter effluent) was moved to the same day as sample collection at location S4 (lagoon influent). Collecting samples on the same day allowed correlation of total suspended solids data collected at Bag Filter No. 1 and from the lagoon influent (discharge from all four bag filters).
- Collected a solids sample from Bag Filter No.1 (S11) at the direction of the EPA TOM to assess the content and leachability of metals in the treatment system waste stream. The solids sample was analyzed for total metals and metals after TCLP extraction, SPLP extraction, and California DI WET extraction. The solids sample was also analyzed for total solids and percent moisture in order to estimate the likely increase in metals concentration after drying.

5.2 Summary of Data Validation and PARCC Criteria Evaluation

The critical data quality parameters evaluated during data validation include precision, accuracy, representativeness, completeness, and comparability (PARCC). Evaluation of these critical parameters provides insight on the quality of the data and is essential in determining whether the data is of sufficient quality to meet project objectives. A summary of the data validation for the SITE demonstration data and an evaluation of the PARCC parameters for the primary target analytes are presented below.

Based on data validation, only two metals results were rejected in the samples analyzed. Because the laboratory failed to analyze an SPLP leachate method blank for one SDG, detected results for arsenic and chromium were rejected in the SPLP leachate extract for sludge sample 3-BP-08-2-S11-S-G. No other sample results were affected. In addition to the rejected data, some metals data were qualified as estimated based on other QC issues. QC issues resulting in qualified data typically consisted of problems with initial and continuing calibration, calibration and method blank contamination, inductively coupled plasma (ICP) interference check sample analysis, percent recovery and relative percent difference values outside of acceptable values, ICP serial dilution problems, and contract required detection limits (CRDL) standard recovery problems, and/or method blank contamination. An evaluation of the PARCC parameters follows.

Precision: Precision for the SITE demonstration data was evaluated through the analysis of matrix duplicates (MD) samples for metals. The precision goal for MD samples was established at less than or equal to 20 percent for relative percent difference (RPD). Over the duration of the SITE demonstration, a total of 20 aqueous samples and four sludge samples were collected from the treatment systems and analyzed in duplicate. Where one or both metals results in a duplicate pair were below the practical quantitation limit (PQL) or not detected, the RPD was not calculated. Out of the five primary target metals and the five secondary water quality indicator metals, RPDs for arsenic, cadmium, chromium, copper, iron, lead, selenium, and/or zinc exceeded the 20 percent RPD criteria in many samples. Corresponding metals data for associated samples within each SDG were qualified as estimated based on duplicate precision problems; however, no data was rejected.

Accuracy: Accuracy for the SITE demonstration data was evaluated through the analysis of matrix spike (MS) samples for the metals analyses. The accuracy goal for MS samples was established at 75 to 125 percent for percent recovery. Over the duration of the SITE demonstration, a total of 17 aqueous samples were collected from the lime treatment systems and analyzed as MS samples. In addition, two sludge samples and six metals leachate samples were analyzed as MS samples. No data for the primary target metals or the secondary water quality indicator metals were qualified based on MS recovery problems. However, in several MS samples poor spike recoveries were observed when metals concentrations in the sample greatly exceeded the spike concentration. In several of the MS samples where poor recoveries were observed for aluminum, arsenic, iron, and/or nickel, the concentrations of these target metals in the samples exceeded four times the spike concentration. Based on EPA guidance (EPA 1995), sample data were not qualified based on poor spike recoveries for these samples.

Representativeness: Representativeness expresses the degree to which sample data accurately and precisely represent the characteristics of a population, parameter variations at a

sampling point, or an environmental condition that they are intended to represent. Representativeness is a qualitative parameter; therefore, no specific criteria must be met. Representative data were obtained during the SITE demonstration through selection of proper sampling locations and analytical methods based on the project objectives and sampling program described in Section 2.3. As specified in the TEP/QAPPs, proper collection and handling of samples avoided cross contamination and minimized analyte losses. The application of standardized laboratory procedures also facilitated generation of representative data.

To aid in the evaluation of sample representativeness, laboratory-required method blank samples were analyzed and evaluated for the presence of contaminants. Sample data determined to be non-representative by comparison with method blank data was qualified, as described earlier in this section. With the exception of the rejected metals data, the data collected during the SITE demonstration are deemed representative of the chemical concentrations, physical properties, and other non-analytical parameters that were being sampled or documented.

Completeness: Completeness is a measure of the percentage of project-specific data deemed valid. Valid data are obtained when samples are collected and analyzed in accordance with QC procedures outlined in the TEP/QAPPs and when none of the quality control (QC) criteria that affect data usability are significantly exceeded. The rejected data discussed above are deemed invalid and affect the completeness goal. Other factors not related to the validity of the data can also affect completeness, such as lost or broken samples, missed sampling events, or operational changes by the system operator.

In 2003, the active lime treatment system was evaluated primarily during monophasic operations; however, a single day sampling event was conducted during biphasic operations. A complete evaluation of the unit operations of the system operated in biphasic mode was conducted during a single event in 2003 for comparison to the 2002 biphasic evaluation period.

Evaluation of the system during monophasic operations in 2003 represented a significant departure from the TEP/QAPP; however, the sample design was retained and only modified where a sampling location was no longer valid or duplicative. The duration of the monophasic evaluation period was also reduced from a planned six week period to four weeks by the system operator.

In 2002, the planned six week evaluation period of the active lime treatment system during biphasic operations, though limited in scope, was fully achieved. Two planned sampling events were canceled due to system failures; however, two additional sampling events were added to the schedule. The planned four week evaluation period of the semi-passive alkaline treatment lagoon, though limited in scope, was also fully achieved.

As specified in the TEP/QAPPs, the project completeness goal for the SITE demonstration was 90 percent. Based on an evaluation of the data that was collected and analyzed and other documentation, completeness for the project was greater than 99 percent. Deviations from the TEP/QAPP due to unplanned changes in system operation by the system operator did not impact the validity of the data. Instead, the unplanned changes provided an opportunity to evaluate different modes of system operation and system response to changes in source water chemistry, flow rate, and HRT.

Comparability: The comparability objective determines whether analytical conditions are sufficiently uniform throughout the duration of the project to ensure that reported data are consistent. For the SITE demonstration, the generation of uniform data was ensured through adherence of the contracted laboratory to specified analytical methods, QC criteria, standardized units of measure, and standardized electronic deliverables in accordance with the TEP/QAPPs. Comparability for the SITE demonstration data was also ensured through third party validation. As a result of these efforts, no data comparability issues were documented by the project team for this project.

SECTION 6
TECHNOLOGY STATUS

The technology associated with the active and semi-passive lime treatment systems is not proprietary, nor are proprietary reagents or equipment required for system operation. Both systems have been demonstrated at full-scale and are currently operational at Leviathan Mine. The treatment systems are undergoing continuous refinement and optimization to address lime delivery and scaling problems. The semi-passive alkaline lagoon treatment system has recently been reconfigured to include a rotating cylinder treatment system (RCTS) in place of the reaction tanks. Lime is combined with ARD in a mixing tank, mixed for a short period of time, then pumped to the RCTS for extend aeration. The new RCTS has decreased the lime requirement by over 50 percent, resulting in reagent and solids disposal cost savings of $0.52 per 1,000 liters (Tsukamoto 2004). Because of the success of lime treatment at Leviathan Mine, the state of California and ARCO are also evaluating the potential effectiveness, implementability, and costs for year-round treatment. Applied to other AMD- or ARD-impacted sites, the lime treatment systems would require only bench scale testing to assess lime requirement and flocculent dosage (as applicable) prior to design and construction of operational systems. The systems are fully scalable, requiring only modification of reaction tank and clarifier size to achieve the required unit operation and system HRT necessary for lime contact and precipitate settling. The active lime treatment system has been operated at flows ranging from 210.5 to 663 L/min using the same process equipment. Lower flow rates (62 to 111 L/min) are preferable for operation of the semi-passive alkaline treatment lagoon due to limitations on the number of bag filters required for initial precipitate removal.

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APPENDIX A
SAMPLE COLLECTION AND ANALYSIS TABLES

Table A-1. 2003 Sample Register for the Active Lime Treatment System, Monophasic Operations

Sample ID	Date	Location	Filtered?	Project Objective	Metals	TSS	TDS	Sulfate	Alkalinity	Hardness	Comments
3-BP-01-2-S01-W-C	6/24/2003	Influent	No	P1, P2, SG2	x	x	x	x	x	x	
3-BP-01-2-S01-W-C-F	6/24/2003	Influent	Yes	P1, P2	x						
3-BP-01-2-S02-W-C	6/24/2003	Effluent	No	P1, P2, SG2	x	x	x	x	x	x	
3-BP-01-2-S02-W-C-F	6/24/2003	Effluent	Yes	P1, P2	x						MS/MD
3-BP-01-4-S01-W-C	6/26/2003	Effluent	No	P1, P2	x						
3-BP-01-4-S01-W-C-F	6/26/2003	Influent	Yes	P1, P2	x						
3-BP-01-4-S02-W-C	6/26/2003	Effluent	No	P1, P2	x						
3-BP-01-4-S02-W-C-F	6/26/2003	Effluent	Yes	P1, P2	x						
3-BP-02-2-S01-W-C	7/1/2003	Influent	No	P1, P2	x						
3-BP-02-2-S01-W-C-F	7/1/2003	Influent	Yes	P1, P2	x						
3-BP-02-2-S02-W-C	7/1/2003	Effluent	No	P1, P2	x						
3-BP-02-2-S02-W-C-F	7/1/2003	Effluent	Yes	P1, P2	x						
3-BP-02-4-S01-W-C	7/3/2003	Influent	No	P1, P2, SG1	x	x	x	x	x	x	
3-BP-02-4-S01-W-C-F	7/3/2003	Influent	Yes	P1, P2	x						
3-BP-02-4-S02-W-C	7/3/2003	Effluent	No	P1, P2, SG1	x	x	x	x	x	x	
3-BP-02-4-S02-W-C-F	7/3/2003	Effluent	Yes	P1, P2	x						MS/MD
3-BP-02-4-S03-W-C	7/3/2003	Phase I Reactor Effluent	No	SG1	x	x	x	x	x	x	
3-BP-02-4-S03-W-C-F	7/3/2003	Phase I Reactor Effluent	Yes	SG1	x						
3-BP-02-4-S04-W-C	7/3/2003	Phase II Reactor Effluent	No	SG1	x	x	x	x	x	x	
3-BP-02-4-S04-W-C-F	7/3/2003	Phase II Reactor Effluent	Yes	SG1	x						
3-BP-02-4-S05-W-C	7/3/2003	Phase II Reactor Influent	No	SG1	x	x	x	x	x	x	MS/MD
3-BP-02-4-S06-W-C	7/3/2003	Clarifier II Settled Solids	No	SG1	x	x	x	x	x	x	
3-BP-02-4-S06-W-C-F	7/3/2003	Clarifier II Settled Solids	Yes	SG1	x						
3-BP-02-4-S14-W-C	7/3/2003	Phase II Clarifier Influent	No	SG1	x	x	x	x	x	x	
3-BP-02-4-S14-W-C-F	7/3/2003	Phase II Clarifier Influent	Yes	SG1	x						
3-BP-03-3-S01-W-C	7/9/2003	Influent	No	P1, P2, SG1	x	x	x	x	x	x	
3-BP-03-3-S01-W-C-F	7/9/2003	Influent	Yes	P1, P2	x						
3-BP-03-3-S02-W-C	7/9/2003	Effluent	No	P1, P2, SG1	x	x	x	x	x	x	
3-BP-03-3-S02-W-C-F	7/9/2003	Effluent	Yes	P1, P2	x						
3-BP-03-4-P4-W-G	7/10/2003	Pond 4 Discharge	No	P1, P2	x			x	x	x	

Table A-1. 2003 Sample Register for the Active Lime Treatment System, Monophasic Operations (continued)

Sample ID	Date	Location	Filtered?	Project Objective	Metals	TSS	TDS	Sulfate	Alkalinity	Hardness	Comments
3-BP-03-4-P4-W-G-F	7/10/2003	Pond 4 Discharge	Yes	P1, P2	x						
3-BP-03-4-S01-W-C	7/10/2003	Influent	No	P1, P2	x						
3-BP-03-4-S01-W-C-F	7/10/2003	Influent	Yes	P1, P2	x						
3-BP-03-4-S02-W-C	7/10/2003	Effluent	No	P1, P2	x						
3-BP-03-4-S02-W-C-F	7/10/2003	Effluent	Yes	P1, P2	x						
3-BP-03-4-S06-W-C	7/10/2003	Clarifier II Settled Solids	No	SG3	x	x	x				
3-BP-03-4-S06-W-C-F	7/10/2003	Clarifier II Settled Solids	Yes	SG3	x						
3-BP-03-4-S10-W-G	7/10/2003	Filter Press Decant	No	SG4	x	x	x	x	x	x	
3-BP-03-4-S13-W-C	7/10/2003	Clarifier I Settled Solids	No	SG4	x	x	x				
3-BP-03-4-S13-W-C-F	7/10/2003	Clarifier I Settled Solids	Yes	SG4	x						
3-BP-03-4-S14-W-C	7/10/2003	Phase II Clarifier Influent	No	SG2	x	x	x				
3-BP-03-4-S14-W-C-F	7/10/2003	Phase II Clarifier Influent	Yes	SG2	x						
3-BP-04-3-S01-W-C	7/16/2003	Influent	No	P1, P2, SG1	x	x	x	x	x	x	
3-BP-04-3-S01-W-C-F	7/16/2003	Influent	Yes	P1, P2	x						
3-BP-04-3-S02W-C	7/16/2003	Effluent	No	P1, P2, SG1	x	x	x	x	x	x	
3-BP-04-3-S02-W-C-F	7/16/2003	Effluent	Yes	P1, P2	x						MS/MD

MS/MD = Matrix spike/matrix duplicate TDS = Total dissolved solids TSS = Total suspended solids

Sample ID	Date	Location	Filtered?	Project Objective	Metals	TCLP Metals	WET Metals	SPLP Metals	Moisture Moisture	Comments
3-BP-02-4-S11-SL-G	7/3/2003	Filter Cake	---	SG4	x	x	x	x	x	MS/MD
3-BP-03-4-S13-W-G	7/10/2003	Clarifier I Settled Solids	---	SG4	x	x	x	x	x	

MS/MD = Matrix spike/matrix duplicate TCLP = Toxicity characteristic leaching procedure
SPLP = Synthetic precipitation and leaching procedure WET = Waste extraction test

Table A-2. 2002 Sample Register for the Active Lime Treatment System, Monophasic Trial

Sample ID	Date	Location	Filtered?	Project Objective	Water Metals	Total Solids	Solids Metals	TCLP Metals	WET Metals	SPLP Metals	Moisture
MP-6-4-S1-G	8/21/2002	Influent	No	P1, P2	x						
MP-6-4-S1-G-F	8/21/2002	Influent	Yes	P1, P2	x						
MP-6-4-S2-G	8/21/2002	Effluent	No	P1, P2	x						
MP-6-4-S2-G-F	8/21/2002	Effluent	Yes	P1, P2	x						
MP-6-4-S2-SD	8/21/2002	Clarifier II Settled Solids	No	SG4		x	x	x	x	x	x

SPLP = Synthetic precipitation and leaching procedure TCLP = Toxicity characteristic leaching procedure WET = Waste extraction test

Table A-3. 2003 Sample Register for the Active Lime Treatment System, Biphasic Operations

Sample ID	Date	Location	Filtered?	Project Objective	Metals	TSS	TDS	Sulfate	Alkalinity	Hardness	Comments
3-BP-08-2-S01-W-C	8/12/2003	Influent	No	P1, P2, SG1	x	x	x	x	x	x	
3-BP-08-2-S01-W-C-F	8/12/2003	Influent	Yes	P1, P2	x						
3-BP-08-2-S02-W-C	8/12/2003	Effluent	No	P1, P2, SG1	x	x	x	x	x	x	
3-BP-08-2-S02-W-C-F	8/12/2003	Effluent	Yes	P1, P2	x						MS/MD
3-BP-08-2-S03-W-C	8/12/2003	Phase I Reactor Effluent	No	SG1	x	x	x	x	x	x	
3-BP-08-2-S03-W-C-F	8/12/2003	Phase I Reactor Effluent	Yes	SG1	x						
3-BP-08-2-S04-W-C	8/12/2003	Phase II Reactor Effluent	No	SG1	x	x	x	x	x	x	
3-BP-08-2-S04-W-C-F	8/12/2003	Phase II Reactor Effluent	Yes	SG1	x						
3-BP-08-2-S05-W-C	8/12/2003	Phase II Reactor Influent	No	SG1	x	x	x	x	x	x	MS/MD
3-BP-08-2-S05-W-C-F	8/12/2003	Phase II Reactor Influent	Yes	SG1	x						
3-BP-08-2-S06-W-C	8/12/2003	Clarifier II Settled Solids	No	SG1	x	x	x	x	x	x	
3-BP-08-2-S06-W-C-F	8/12/2003	Clarifier II Settled Solids	Yes	SG1	x						
3-BP-08-2-S10-W-G	8/12/2003	Filter Press Decant	No	SG1	x	x	x	x	x	x	
3-BP-08-2-S13-W-G	8/12/2003	Phase I Flash Floc Tank	No	SG1		x	x				
3-BP-08-2-S14-W-G	8/12/2003	Phase II Flash Floc Tank	No	SG1		x	x				
3-BP-08-2-S16-W-C	8/12/2003	Clarifier I Settled Solids	No	SG3	x	x	x	x	x	x	
3-BP-08-2-S16-W-C-F	8/12/2003	Clarifier I Settled Solids	Yes	SG3	x						

MS/MD = Matrix spike/matrix duplicate TDS = Total dissolved solids TSS = Total suspended solids

Sample ID	Date	Location	Filtered?	Project Objective	Metals	TCLP Metals	WET Metals	SPLP Metals	Moisture	Comments
3-BP-08-2-S11-S-G	8/12/2003	Filter Cake	NA	SG4	x	x	x	x	x	MS/MD
3-BP-16-3-S12-SL-C	10/1/2003	Pit Clarifier	No	SG3, SG4	x	x	x	x	x	

MS/MD = Matrix spike/matrix duplicate TCLP = Toxicity characteristic leaching procedure
SPLP = Synthetic precipitation and leaching procedure WET = Waste extraction test

Table A-4. 2002 Sample Register for the Active Lime Treatment System, Biphasic Operations

Sample ID	Date	Location	Filtered?	Project Objective	Metals	TSS	TDS	Sulfate	Alkalinity	Total Solids	Comments
BP-01-4-S01-W-C	7/18/2002	Influent	No	P1, P2	x						
BP-01-4-S01-W-C-F	7/18/2002	Influent	Yes	P1, P2	x						
BP-01-4-S02-W-C	7/18/2002	Effluent	No	P1, P2	x						
BP-01-4-S02-W-C-F	7/18/2002	Effluent	Yes	P1, P2	x						
BP-02-2-S01-W-C	7/23/2002	Influent	No	P1, P2, SG3	x	x	x	x	x		
BP-02-2-S01-W-C-F	7/23/2002	Influent	Yes	P1, P2	x						
BP-02-2-S02-W-C	7/23/2002	Effluent	No	P1, P2, SG3	x	x	x	x	x		
BP-02-2-S02-W-C-F	7/23/2002	Effluent	Yes	P1, P2	x						
BP-02-4-S01-W-C	7/25/2002	Influent	No	P1, P2, SG3	x	x	x	x	x		
BP-02-4-S01-W-C-F	7/25/2002	Influent	Yes	P1, P2	x						
BP-02-4-S02-W-C	7/25/2002	Effluent	No	P1, P2, SG3	x	x	x	x	x		MS/MD
BP-02-4-S02-W-C-F	7/25/2002	Effluent	Yes	P1, P2	x						
BP-03-2-S01-W-C	7/30/2002	Influent	No	P1, P2	x						
BP-03-2-S01-W-C-F	7/30/2002	Influent	Yes	P1, P2	x						
BP-03-2-S02-W-C	7/30/2002	Effluent	No	P1, P2	x						
BP-03-2-S02-W-C-F	7/30/2002	Effluent	Yes	P1, P2	x						
BP-04-4-S01-W-C	8/8/2002	Influent	No	P1, P2, SG3	x	x	x	x	x		MS/MD
BP-04-4-S01-W-C-F	8/8/2002	Influent	Yes	P1, P2	x						
BP-04-4-S02-W-C	8/8/2002	Effluent	No	P1, P2, SG3	x	x	x	x	x		MS/MD
BP-04-4-S02-W-C-F	8/8/2002	Effluent	Yes	P1, P2	x						
BP-05-2-S01-W-C	8/13/2002	Influent	No	P1, P2	x						
BP-05-2-S01-W-C-F	8/13/2002	Influent	Yes	P1, P2	x						
BP-05-2-S02-W-C	8/13/2002	Effluent	No	P1, P2	x						
BP-05-2-S02-W-C-F	8/13/2002	Effluent	Yes	P1, P2	x						MS/MD
BP-06-2-S01-W-C	8/20/2002	Influent	No	P1, P2, SG3	x	x	x	x	x		
BP-06-2-S01-W-C-F	8/20/2002	Influent	Yes	P1, P2	x						
BP-06-2-S02-W-C	8/20/2002	Effluent	No	P1, P2, SG3	x	x	x	x	x		
BP-06-2-S02-W-C-F	8/20/2002	Effluent	Yes	P1, P2	x						MS/MD
BP-06-2-S02-W-F	8/20/2002	Effluent	Yes	SG1, SG2	x						
BP-06-2-S02-W-1	8/20/2002	Effluent	No	SG1, SG2		x				x	
BP-06-2-S02-W-2	8/20/2002	Effluent	No	SG1, SG2		x				x	
BP-06-2-S03-W-C	8/20/2002	Phase I reactor effluent	No	SG1, SG2	x						
BP-06-2-S03-W-C-F	8/20/2002	Phase I reactor effluent	Yes	SG1, SG2	x						
BP-06-2-S04-W-C	8/20/2002	Phase II reactor effluent	No	SG1, SG2	x						

Table A-4. 2002 Sample Register for the Active Lime Treatment System, Biphasic Operations (continued)

Sample ID	Date	Location	Filtered?	Project Objective	Metals	TSS	TDS	Sulfate	Alkalinity	Total Solids	Comments
BP-06-2-S04-W-C-F	8/20/2002	Phase II reactor effluent	Yes	SG1, SG2	x						
BP-06-2-S05-W-C	8/20/2002	Phase II reactor influent	No	SG1, SG2	x						
BP-06-2-S05-W-C-F	8/20/2002	Phase II reactor influent	Yes	SG1, SG2	x						MS/MD
BP-06-2-S05-W-1	8/20/2002	Phase II reactor influent	No	SG1, SG2		x				x	
BP-06-2-S05-W-2	8/20/2002	Phase II reactor influent	No	SG1, SG2		x				x	
BP-06-2-S07-W-C	8/20/2002	Pit Clarifier Influent	No	SG1, SG2	x						
BP-06-2-S07-W-C-F	8/20/2002	Pit Clarifier Influent	Yes	SG1, SG2	x						
BP-06-2-S07-W-1	8/20/2002	Pit Clarifier Influent	No	SG1, SG2		x				x	
BP-06-2-S07-W-2	8/20/2002	Pit Clarifier Influent	No	SG1, SG2		x				x	
BP-06-2-S11-W-C	8/20/2002	Sludge Tank Overflow	No	SG1, SG2	x						
BP-06-4-S01-W-C	8/22/2002	Influent	No	P1, P2	x						
BP-06-4-S01-W-C-F	8/22/2002	Influent	Yes	P1, P2	x						
BP-06-4-S02-W-C	8/22/2002	Effluent	No	P1, P2	x						
BP-06-4-S02-W-C-F	8/22/2002	Effluent	Yes	P1, P2	x						
BP-07-2-S01-W-C	8/27/2002	Influent	No	P1, P2, SG3	x	x	x	x	x		
BP-07-2-S01-W-C-F	8/27/2002	Influent	Yes	P1, P2	x						
BP-07-2-S02-W-C	8/27/2002	Effluent	No	P1, P2, SG3	x	x	x	x	x		
BP-07-2-S02-W-C-F	8/27/2002	Effluent	Yes	P1, P2	x						MS/MD
BP-07-2-S12-W-G	8/27/2002	Filter Press Effluent	No	SG2, SG4	x						
BP-07-4-S01-W-C	8/29/2002	Influent	No	P1, P2	x						
BP-07-4-S01-W-C-F	8/29/2002	Influent	Yes	P1, P2	x						
BP-07-4-S02-W-C	8/29/2002	Effluent	No	P1, P2	x						
BP-07-4-S02-W-C-F	8/29/2002	Effluent	Yes	P1, P2	x						
BP-08-3-S01-W-C	9/4/2002	Influent	No	P1, P2, SG3	x	x	x	x	x		
BP-08-3-S01-W-C-F	9/4/2002	Influent	Yes	P1, P2	x						
BP-08-3-S02-W-C	9/4/2002	Effluent	No	P1, P2, SG3	x	x	x	x	x		
BP-08-3-S02-W-C-F	9/4/2002	Effluent	Yes	P1, P2	x						MS/MD
BP-08-3-FB	9/4/2002	Field Blank	No	QA/QC	x						
BP-08-3-ER-F	9/4/2002	Equipment Rinseate	Yes	QA/QC	x						

MS/MD = Matrix spike/matrix duplicate TDS = Total dissolved solids TSS = Total suspended solids

Table A-4. 2002 Sample Register for the Active Lime Treatment System, Biphasic Operations (continued)

Sample ID	Date	Location	Filtered?	Project Objective	Moisture	Metals	TCLP Metals	WET Metals	SPLP Metals	Total Solids	Comments
BP-07-2-S7-S-G	8/27/2002	Pit Clarifier Sludge	No	SG2, SG4	x	x	x	x	x	x	
BP-07-2-S13-S-G	8/27/2002	Filter Cake	No	SG2, SG4	x	x	x	x	x	x	

SPLP = Synthetic precipitation and leaching procedure TCLP = Toxicity characteristic leaching procedure WET = Waste extraction test

Table A-5. 2002 Sample Register for the Semi-Passive Alkaline Lagoon Treatment System

Sample ID	Date	Location	Filtered?	Project Objective	Metals	TSS	TDS	Sulfate	Alkalinity	Comments
AL-01-4-S01-W-C	7/18/2002	Influent	No	P1, P2	x					
AL-01-4-S01-W-C-F	7/18/2002	Influent	Yes	P1, P2	x					
AL-01-4-S02-W-C	7/18/2002	Effluent	No	P1, P2	x					MS/MD
AL-01-4-S02-W-C-F	7/18/2002	Effluent	Yes	P1, P2	x					
AL-02-2-S01-W-C	7/23/2002	Influent	No	P1, P2, SG3	x	x	x	x	x	
AL-02-2-S01-W-C-F	7/23/2002	Influent	Yes	P1, P2	x					
AL-02-2-S02-W-C	7/23/2002	Effluent	No	P1, P2, SG3	x	x	x	x	x	
AL-02-2-S02-W-C-F	7/23/2002	Effluent	Yes	P1, P2	x					
AL-02-2-S04-W-C	7/23/2002	All Bag Filter Effluent	No	SG2, SG4	x	x	x			
AL-02-2-S04-W-C-F	7/23/2002	All Bag Filter Effluent	Yes	SG2, SG4	x					
AL-02-2-S11a-W-C	7/23/2002	All Bag Filter Influent	No	SG2, SG4		x				
AL-02-2-S11b-W-C	7/23/2002	Bag filter #1 Effluent	No	SG2, SG4		x				
AL-02-4-S01-W-C	7/25/2002	Influent	No	P1, P2	x					
AL-02-4-S01-W-C-F	7/25/2002	Influent	Yes	P1, P2	x					
AL-02-4-S02-W-C	7/25/2002	Effluent	No	P1, P2	x					
AL-02-4-S02-W-C-F	7/25/2002	Effluent	Yes	P1, P2	x					MS/MD
AL-03-2-S01-W-C	7/30/2002	Influent	No	P1, P2, SG3	x	x	x	x	x	
AL-03-2-S01-W-C-F	7/30/2002	Influent	Yes	P1, P2	x					
AL-03-2-S02-W-C	7/30/2002	Effluent	No	P1, P2, SG3	x	x	x	x	x	MS/MD
AL-03-2-S02-W-C-F	7/30/2002	Effluent	Yes	P1, P2	x					
AL-03-2-S3C-W-C	7/30/2002	All Bag Filter Influent	No	SG1	x	x				MS/MD
AL-03-2-S3C-W-C-F	7/30/2002	All Bag Filter Influent	Yes	SG1	x					
AL-03-2-S04-W-C	7/30/2002	All Bag Filter Effluent	No	SG2, SG4	x	x	x			
AL-03-2-S04-W-C-F	7/30/2002	All Bag Filter Effluent	Yes	SG2, SG4	x					
AL-03-2-S05-W-C	7/30/2002	Cell 1	No	SG1	x					
AL-03-2-S06-W-C	7/30/2002	Cell 2	No	SG1	x					
AL-03-2-S11B-W-C	7/30/2002	Bag filter #1 Effluent	No	SG2, SG4		x				
AL-03-4-S01-W-C	8/1/2002	Influent	No	P1, P2	x					
AL-03-4-S01-W-C-F	8/1/2002	Influent	Yes	P1, P2	x					
AL-03-4-S02-W-C	8/1/2002	Effluent	No	P1, P2	x					
AL-03-4-S02-W-C-F	8/1/2002	Effluent	Yes	P1, P2	x					
AL-04-2-S01-W-C	8/6/2002	Influent	No	P1, P2, SG3	x	x	x	x	x	
AL-04-2-S01-W-C-F	8/6/2002	Influent	Yes	P1, P2	x					
AL-04-2-S02-W-C	8/6/2002	Effluent	No	P1, P2, SG3	x	x	x	x	x	MS/MD

Table A-5. 2002 Sample Register for the Semi-Passive Alkaline Lagoon Treatment System (continued)

Sample ID	Date	Location	Filtered?	Project Objective	Metals	TSS	TDS	Sulfate	Alkalinity	Comments
AL-04-2-S02-W-C-F	8/6/2002	Effluent	Yes	P1, P2	x					
AL-04-2-S04-W-C	8/6/2002	All Bag Filter Effluent	No	SG2, SG4	x	x	x			
AL-04-2-S04-W-C-F	8/6/2002	All Bag Filter Effluent	Yes	SG2, SG4	x					
AL-04-2-S11a-W-C	8/6/2002	All Bag Filter Influent	No	SG2, SG4		x				
AL-04-2-S11b-W-C	8/6/2002	Bag filter #1 Effluent	No	SG2, SG4		x				
AL-04-4-S01-W-C	8/8/2002	Influent	No	P1, P2	x					
AL-04-4-S01-W-C-F	8/8/2002	Influent	Yes	P1, P2	x					
AL-04-4-S02-W-C	8/8/2002	Effluent	No	P1, P2	x					
AL-04-4-S02-W-C-F	8/8/2002	Effluent	Yes	P1, P2	x					MS/MD
AL-05-2-S01-W-C	8/13/2002	Influent	No	P1, P2, SG3	x	x	x	x	x	MS/MD
AL-05-2-S01-W-C-F	8/13/2002	Influent	Yes	P1, P2	x					
AL-05-2-S02-W-C	8/13/2002	Effluent	No	P1, P2, SG3	x	x	x	x	x	
AL-05-2-S02-W-C-F	8/13/2002	Effluent	Yes	P1, P2	x					
AL-05-2-S03C-W-C	8/13/2002	All Bag Filter Influent	No	SG1		x				
AL-05-2-S04-W-C	8/13/2002	All Bag Filter Effluent	No	SG2, SG4	x	x	x			
AL-05-2-S04-W-C-F	8/13/2002	All Bag Filter Effluent	Yes	SG2, SG4	x					
AL-05-2-S11B-W-C	8/13/2002	Bag filter #1 Effluent	No	SG2, SG4		x				

MS/MD = Matrix spike/matrix duplicate TDS = Total dissolved solids TSS = Total suspended solids

Sample ID	Date	Location	Filtered?	Project Objective	Metals	TCLP Metals	WET Metals	SPLP Metals	Total Solids	Moisture
AL-07-2-S11-S-G	8/27/2002	Bag filter #1 Sludge	No	SG2, SG5	x	x	x	x	x	x

SPLP = Synthetic precipitation and leaching procedure TCLP = Toxicity characteristic leaching procedure WET = Waste extraction test

APPENDIX B
DATA USED TO EVALUATE PROJECT PRIMARY OBJECTIVES

Table B-1. Data Used to Evaluate Project Objectives for the Active Lime Treatment System, Monophasic Operations

Sample Number[1]	Sample Date	Composite or Grab?	Analyte	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	4-Day Average Effluent Concentration (µg/L)
3-BP-01-2-S0X-W-C-F	6/24/2003	Composite	Aluminum	107,000	875	
3-BP-01-4-S0X-W-C-F	6/24/2003	Composite	Aluminum	105,000	1,090	
3-BP-02-2-S0X-W-C-F	7/1/2003	Composite	Aluminum	114,000	511	
3-BP-02-4-S0X-W-C-F	7/3/2003	Composite	Aluminum	119,000	584	765
3-BP-03-3-S0X-W-C-F	7/9/2003	Composite	Aluminum	107,000	193	595
3-BP-03-4-S0X-W-C-F	7/10/2003	Composite	Aluminum	98,600	575	466
3-BP-04-3-S0X-W-C-F	7/16/2003	Composite	Aluminum	104,000	604	489
3-BP-01-2-S0X-W-C-F	6/24/2003	Composite	Arsenic	3,430	8	
3-BP-01-4-S0X-W-C-F	6/24/2003	Composite	Arsenic	3,310	10.8	
3-BP-02-2-S0X-W-C-F	7/1/2003	Composite	Arsenic	3,410	7.1	
3-BP-02-4-S0X-W-C-F	7/3/2003	Composite	Arsenic	3,470	9 7	8.9
3-BP-03-3-S0X-W-C-F	7/9/2003	Composite	Arsenic	2,970	3.6	7.8
3-BP-03-4-S0X-W-C-F	7/10/2003	Composite	Arsenic	2,810	1.8U	5.6
3-BP-04-3-S0X-W-C-F	7/16/2003	Composite	Arsenic	3,250	2.9	4.5
3-BP-01-2-S0X-W-C-F	6/24/2003	Composite	Cadmium	16.4	0.21U	
3-BP-01-4-S0X-W-C-F	6/24/2003	Composite	Cadmium	15.5	0.21U	
3-BP-02-2-S0X-W-C-F	7/1/2003	Composite	Cadmium	46.3	0.16U	
3-BP-02-4-S0X-W-C-F	7/3/2003	Composite	Cadmium	45.7	0.16U	NC
3-BP-03-3-S0X-W-C-F	7/9/2003	Composite	Cadmium	23.2	0.16U	NC
3-BP-03-4-S0X-W-C-F	7/10/2003	Composite	Cadmium	22.6	0.16U	NC
3-BP-04-3-S0X-W-C-F	7/16/2003	Composite	Cadmium	13.2	0.21U	NC
3-BP-01-2-S0X-W-C-F	6/24/2003	Composite	Chromium	299	2.4	
3-BP-01-4-S0X-W-C-F	6/24/2003	Composite	Chromium	293	2.1	
3-BP-02-2-S0X-W-C-F	7/1/2003	Composite	Chromium	629	1.3	
3-BP-02-4-S0X-W-C-F	7/3/2003	Composite	Chromium	327	0.67	1.6
3-BP-03-3-S0X-W-C-F	7/9/2003	Composite	Chromium	280	1.5	1.4
3-BP-03-4-S0X-W-C-F	7/10/2003	Composite	Chromium	266	11.6	3.8
3-BP-04-3-S0X-W-C-F	7/16/2003	Composite	Chromium	291	1.7	3.9
3-BP-01-2-S0X-W-C-F	6/24/2003	Composite	Copper	536	5 4	
3-BP-01-4-S0X-W-C-F	6/24/2003	Composite	Copper	526	3.6	
3-BP-02-2-S0X-W-C-F	7/1/2003	Composite	Copper	539	2.1	
3-BP-02-4-S0X-W-C-F	7/3/2003	Composite	Copper	549	1.9U	3 3
3-BP-03-3-S0X-W-C-F	7/9/2003	Composite	Copper	476	1 9U	2.4
3-BP-03-4-S0X-W-C-F	7/10/2003	Composite	Copper	434	1.9U	2.0
3-BP-04-3-S0X-W-C-F	7/16/2003	Composite	Copper	454	4.7	2.6
3-BP-01-2-S0X-W-C-F	6/24/2003	Composite	Iron	392,000	5.7	
3-BP-01-4-S0X-W-C-F	6/24/2003	Composite	Iron	456,000	350	
3-BP-02-2-S0X-W-C-F	7/1/2003	Composite	Iron	463,000	336	
3-BP-02-4-S0X-W-C-F	7/3/2003	Composite	Iron	485,000	221	228
3-BP-03-3-S0X-W-C-F	7/9/2003	Composite	Iron	433,000	92.9	250
3-BP-03-4-S0X-W-C-F	7/10/2003	Composite	Iron	421,000	129	195
3-BP-04-3-S0X-W-C-F	7/16/2003	Composite	Iron	545,000	99.9	136

[1] - For the influent sample, X in the sample number = 1; for the effluent sample, X=2
µg/L - Micrograms per liter NC - Not calculated U - Non-detect

Table B-1. Data Used to Evaluate Project Objectives for the Active Lime Treatment System, Monophasic Operations (continued)

Sample Number[1]	Sample Date	Composite or Grab?	Analyte	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	4-Day Average Effluent Concentration (µg/L)
3-BP-01-2-S0X-W-C-F	6/24/2003	Composite	Lead	8.3	1.4U	
3-BP-01-4-S0X-W-C-F	6/24/2003	Composite	Lead	10	1.4U	
3-BP-02-2-S0X-W-C-F	7/1/2003	Composite	Lead	4 4	0.9U	
3-BP-02-4-S0X-W-C-F	7/3/2003	Composite	Lead	2.3	0.9U	1.2
3-BP-03-3-S0X-W-C-F	7/9/2003	Composite	Lead	8.8	0.9U	1.0
3-BP-03-4-S0X-W-C-F	7/10/2003	Composite	Lead	0.9U	0.9U	0.9
3-BP-04-3-S0X-W-C-F	7/16/2003	Composite	Lead	8.7	4.5	1.8
3-BP-01-2-S0X-W-C-F	6/24/2003	Composite	Nickel	2,480	17.3	
3-BP-01-4-S0X-W-C-F	6/24/2003	Composite	Nickel	2,500	20.4	
3-BP-02-2-S0X-W-C-F	7/1/2003	Composite	Nickel	2,670	47.1	
3-BP-02-4-S0X-W-C-F	7/3/2003	Composite	Nickel	2,760	41.8	31 7
3-BP-03-3-S0X-W-C-F	7/9/2003	Composite	Nickel	2,630	113	55.6
3-BP-03-4-S0X-W-C-F	7/10/2003	Composite	Nickel	2,410	68.8	67.7
3-BP-04-3-S0X-W-C-F	7/16/2003	Composite	Nickel	2,470	19.3	60.7
3-BP-01-2-S0X-W-C-F	6/24/2003	Composite	Selenium	2.6U	2.6U	
3-BP-01-4-S0X-W-C-F	6/24/2003	Composite	Selenium	2.6U	2.6U	
3-BP-02-2-S0X-W-C-F	7/1/2003	Composite	Selenium	26.7	1.8U	
3-BP-02-4-S0X-W-C-F	7/3/2003	Composite	Selenium	29.4	1.8U	2.2
3-BP-03-3-S0X-W-C-F	7/9/2003	Composite	Selenium	32.3	1.8U	2.0
3-BP-03-4-S0X-W-C-F	7/10/2003	Composite	Selenium	20	1.8U	1.8
3-BP-04-3-S0X-W-C-F	7/16/2003	Composite	Selenium	2.6U	2.6U	2.0
3-BP-01-2-S0X-W-C-F	6/24/2003	Composite	Zinc	536	12.1	
3-BP-01-4-S0X-W-C-F	6/24/2003	Composite	Zinc	539	7.7	
3-BP-02-2-S0X-W-C-F	7/1/2003	Composite	Zinc	559	3.5	
3-BP-02-4-S0X-W-C-F	7/3/2003	Composite	Zinc	583	2.6	6.5
3-BP-03-3-S0X-W-C-F	7/9/2003	Composite	Zinc	533	7.6	5.4
3-BP-03-4-S0X-W-C-F	7/10/2003	Composite	Zinc	490	3.1	4.2
3-BP-04-3-S0X-W-C-F	7/16/2003	Composite	Zinc	524	2.7	4.0

[1] - For the influent sample, X in the sample number = 1; for the effluent sample, X=2
µg/L - Micrograms per liter U - Non-detect

Table B-2. Data Used to Evaluate Project Objectives for the Active Lime Treatment System, Biphasic Operations

Sample Number[1]	Sample Date	Composite or Grab?	Analyte	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	4-Day Average Effluent Concentration (µg/L)
3-BP-08-2-S0X-W-C-F	8/12/2003	Composite	Aluminum	371,000	2,200	
BP-01-4-S0X-W-C-F	7/18/2002	Composite	Aluminum	354,000	183	
BP-02-2-S0X-W-C-F	7/23/2002	Composite	Aluminum	326,000	1,140	
BP-02-4-S0X-W-C-F	7/25/2002	Composite	Aluminum	330,000	1,690	
BP-03-2-S0X-W-C-F	7/30/2002	Composite	Aluminum	356,000	1,590	1,151
BP-04-4-S0X-W-C-F	8/8/2002	Composite	Aluminum	361,000	2,860	1,820
BP-05-2-SX-W-C-F	8/13/2002	Composite	Aluminum	355,000	1,040	1,795
BP-05-4-S0X-W-C-F	8/15/2002	Composite	Aluminum	384,000	785	1,569
BP-06-2-S0X-W-C-F	8/20/2002	Composite	Aluminum	379,000	370	1,264
BP-06-4-S0X-W-C-F	8/22/2002	Composite	Aluminum	435,000	532	562
BP-07-2-S0X-W-C-F	8/27/2002	Composite	Aluminum	358,000	498	467
BP-07-4-SX-W-C-F	8/29/2002	Composite	Aluminum	458,000	562	531
BP-08-3-SX-W-C-F	9/4/2002	Composite	Aluminum	486,000	1,090	671
3-BP-08-2-S0X-W-C-F	8/12/2003	Composite	Arsenic	2,930	7.7	
BP-01-4-S0X-W-C-F	7/18/2002	Composite	Arsenic	2,270	4.8	
BP-02-2-S0X-W-C-F	7/23/2002	Composite	Arsenic	2,090	9 3	
BP-02-4-S0X-W-C-F	7/25/2002	Composite	Arsenic	1,730	9.8	
BP-03-2-S0X-W-C-F	7/30/2002	Composite	Arsenic	1,970	11.8	8.9
BP-04-4-S0X-W-C-F	8/8/2002	Composite	Arsenic	1,700	7.4	9.6
BP-05-2-SX-W-C-F	8/13/2002	Composite	Arsenic	1,360	10.2	9.8
BP-05-4-S0X-W-C-F	8/15/2002	Composite	Arsenic	1,330	9.6	9.8
BP-06-2-S0X-W-C-F	8/20/2002	Composite	Arsenic	1,890	5.9	8.3
BP-06-4-S0X-W-C-F	8/22/2002	Composite	Arsenic	2,970	8.1	8.5
BP-07-2-S0X-W-C-F	8/27/2002	Composite	Arsenic	1,340	8.5	8.0
BP-07-4-SX-W-C-F	8/29/2002	Composite	Arsenic	3,480	8.5	7.8
BP-08-3-SX-W-C-F	9/4/2002	Composite	Arsenic	4,050	10.1	8.8
3-BP-08-2-S0X-W-C-F	8/12/2003	Composite	Cadmium	55.6	0.35	
BP-01-4-S0X-W-C-F	7/18/2002	Composite	Cadmium	52.1	0.3U	
BP-02-2-S0X-W-C-F	7/23/2002	Composite	Cadmium	48.8	0.5	
BP-02-4-S0X-W-C-F	7/25/2002	Composite	Cadmium	47.9	0.9	
BP-03-2-S0X-W-C-F	7/30/2002	Composite	Cadmium	50.0	0.5	0.6
BP-04-4-S0X-W-C-F	8/8/2002	Composite	Cadmium	50.7	0.5	0.6
BP-05-2-SX-W-C-F	8/13/2002	Composite	Cadmium	51.6	0.8	0.7
BP-05-4-S0X-W-C-F	8/15/2002	Composite	Cadmium	52.8	1.3	0.8
BP-06-2-S0X-W-C-F	8/20/2002	Composite	Cadmium	53.9	0.8	0.9
BP-06-4-S0X-W-C-F	8/22/2002	Composite	Cadmium	60.0	0.8	0.9
BP-07-2-S0X-W-C-F	8/27/2002	Composite	Cadmium	51.5	1.0	1.0
BP-07-4-SX-W-C-F	8/29/2002	Composite	Cadmium	63.6	0.7	0.8
BP-08-3-SX-W-C-F	9/4/2002	Composite	Cadmium	68.3	0.7	0.8

[1] - For the influent sample, X in the sample number = 1; for the effluent sample, X=2
µg/L - Micrograms per liter U - Non-detect

Table B-2. Data Used to Evaluate Project Objectives for the Active Lime Treatment System, Biphasic Operations (continued)

Sample Number[1]	Sample Date	Composite or Grab?	Analyte	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	4-Day Average Effluent Concentration (µg/L)
3-BP-08-2-S0X-W-C-F	8/12/2003	Composite	Chromium	1,000	3.9	
BP-01-4-S0X-W-C-F	7/18/2002	Composite	Chromium	807	1.6	
BP-02-2-S0X-W-C-F	7/23/2002	Composite	Chromium	760	2 8	
BP-02-4-S0X-W-C-F	7/25/2002	Composite	Chromium	738	2.4	
BP-03-2-S0X-W-C-F	7/30/2002	Composite	Chromium	807	2 6	2.4
BP-04-4-S0X-W-C-F	8/8/2002	Composite	Chromium	779	1.7	2.4
BP-05-2-SX-W-C-F	8/13/2002	Composite	Chromium	729	46.3	13.3
BP-05-4-S0X-W-C-F	8/15/2002	Composite	Chromium	785	2.9	13.4
BP-06-2-S0X-W-C-F	8/20/2002	Composite	Chromium	819	2.0	13.2
BP-06-4-S0X-W-C-F	8/22/2002	Composite	Chromium	1,030	2.0	13.3
BP-07-2-S0X-W-C-F	8/27/2002	Composite	Chromium	742	2.1	2.3
BP-07-4-SX-W-C-F	8/29/2002	Composite	Chromium	1,170	1.4	1.9
BP-08-3-SX-W-C-F	9/4/2002	Composite	Chromium	1,240	2.4	2.0
3-BP-08-2-S0X-W-C-F	8/12/2003	Composite	Copper	2,210	5.8	
BP-01-4-S0X-W-C-F	7/18/2002	Composite	Copper	2,350	3.7	
BP-02-2-S0X-W-C-F	7/23/2002	Composite	Copper	2,150	7.3	
BP-02-4-S0X-W-C-F	7/25/2002	Composite	Copper	2,110	10.2	
BP-03-2-S0X-W-C-F	7/30/2002	Composite	Copper	2,300	5.6	6.7
BP-04-4-S0X-W-C-F	8/8/2002	Composite	Copper	2,260	8.6	7.9
BP-05-2-SX-W-C-F	8/13/2002	Composite	Copper	2,180	12.8	9.3
BP-05-4-S0X-W-C-F	8/15/2002	Composite	Copper	2,350	10.2	9.3
BP-06-2-S0X-W-C-F	8/20/2002	Composite	Copper	2,330	6.9	9.6
BP-06-4-S0X-W-C-F	8/22/2002	Composite	Copper	2,660	5.7	8.9
BP-07-2-S0X-W-C-F	8/27/2002	Composite	Copper	2,240	9.2	8.0
BP-07-4-SX-W-C-F	8/29/2002	Composite	Copper	2,850	8.5	7.6
BP-08-3-SX-W-C-F	9/4/2002	Composite	Copper	2,990	10.1	8.4
3-BP-08-2-S0X-W-C-F	8/12/2003	Composite	Iron	553,000	38.4	
BP-01-4-S0X-W-C-F	7/18/2002	Composite	Iron	466,000	39.6	
BP-02-2-S0X-W-C-F	7/23/2002	Composite	Iron	414,000	36.4	
BP-02-4-S0X-W-C-F	7/25/2002	Composite	Iron	435,000	1 9U	
BP-03-2-S0X-W-C-F	7/30/2002	Composite	Iron	485,000	110	47.0
BP-04-4-S0X-W-C-F	8/8/2002	Composite	Iron	398,000	20.2	42.1
BP-05-2-SX-W-C-F	8/13/2002	Composite	Iron	336,000	243	93.8
BP-05-4-S0X-W-C-F	8/15/2002	Composite	Iron	359,000	3.8U	94.3
BP-06-2-S0X-W-C-F	8/20/2002	Composite	Iron	399,000	8.8	69.0
BP-06-4-S0X-W-C-F	8/22/2002	Composite	Iron	541,000	30.5	71.5
BP-07-2-S0X-W-C-F	8/27/2002	Composite	Iron	357,000	3.8U	11.7
BP-07-4-SX-W-C-F	8/29/2002	Composite	Iron	605,000	44.0	21.8
BP-08-3-SX-W-C-F	9/4/2002	Composite	Iron	653,000	3.8U	20.5

[1] - For the influent sample, X in the sample number = 1; for the effluent sample, X=2
µg/L - Micrograms per liter U - Non-detect

Table B-2. Data Used to Evaluate Project Objectives for the Active Lime Treatment System, Biphasic Operations (continued)

Sample Number[1]	Sample Date	Composite or Grab?	Analyte	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	4-Day Average Effluent Concentration (µg/L)
3-BP-08-2-S0X-W-C-F	8/12/2003	Composite	Lead	1 7	4.4	
BP-01-4-S0X-W-C-F	7/18/2002	Composite	Lead	3.9	1 2U	
BP-02-2-S0X-W-C-F	7/23/2002	Composite	Lead	1.2U	1 2U	
BP-02-4-S0X-W-C-F	7/25/2002	Composite	Lead	9 5	2.5	
BP-03-2-S0X-W-C-F	7/30/2002	Composite	Lead	9.0	1.2U	1.5
BP-04-4-S0X-W-C-F	8/8/2002	Composite	Lead	7 7	1.2U	1.5
BP-05-2-SX-W-C-F	8/13/2002	Composite	Lead	12.2	1.4U	1.6
BP-05-4-S0X-W-C-F	8/15/2002	Composite	Lead	6.4	3.6	1.9
BP-06-2-S0X-W-C-F	8/20/2002	Composite	Lead	6.9	1.4U	1.9
BP-06-4-S0X-W-C-F	8/22/2002	Composite	Lead	11.8	1.4U	2.0
BP-07-2-S0X-W-C-F	8/27/2002	Composite	Lead	8.0	3.3	2.4
BP-07-4-SX-W-C-F	8/29/2002	Composite	Lead	10.2	1.4U	1.9
BP-08-3-SX-W-C-F	9/4/2002	Composite	Lead	10.8	1 8	2.0
3-BP-08-2-S0X-W-C-F	8/12/2003	Composite	Nickel	6,490	25	
BP-01-4-S0X-W-C-F	7/18/2002	Composite	Nickel	6,860	17.1	
BP-02-2-S0X-W-C-F	7/23/2002	Composite	Nickel	6,420	31.2	
BP-02-4-S0X-W-C-F	7/25/2002	Composite	Nickel	5,980	17.2	
BP-03-2-S0X-W-C-F	7/30/2002	Composite	Nickel	6,540	21.9	21.9
BP-04-4-S0X-W-C-F	8/8/2002	Composite	Nickel	6,600	7.1	19.4
BP-05-2-SX-W-C-F	8/13/2002	Composite	Nickel	6,490	48.0	23.6
BP-05-4-S0X-W-C-F	8/15/2002	Composite	Nickel	7,080	39.0	29.0
BP-06-2-S0X-W-C-F	8/20/2002	Composite	Nickel	7,040	55.3	37.4
BP-06-4-S0X-W-C-F	8/22/2002	Composite	Nickel	7,890	43.0	46.3
BP-07-2-S0X-W-C-F	8/27/2002	Composite	Nickel	6,720	50.9	47 1
BP-07-4-SX-W-C-F	8/29/2002	Composite	Nickel	8,430	49.8	49.8
BP-08-3-SX-W-C-F	9/4/2002	Composite	Nickel	8,770	38.9	45.7
3-BP-08-2-S0X-W-C-F	8/12/2003	Composite	Selenium	2.6U	2.6U	
BP-01-4-S0X-W-C-F	7/18/2002	Composite	Selenium	10.4	4.0	
BP-02-2-S0X-W-C-F	7/23/2002	Composite	Selenium	4.6	3.7	
BP-02-4-S0X-W-C-F	7/25/2002	Composite	Selenium	5 5	5.3	
BP-03-2-S0X-W-C-F	7/30/2002	Composite	Selenium	2 5U	2.5U	3.9
BP-04-4-S0X-W-C-F	8/8/2002	Composite	Selenium	2 5U	5.3	4.2
BP-05-2-SX-W-C-F	8/13/2002	Composite	Selenium	2 2U	3 7	4 2
BP-05-4-S0X-W-C-F	8/15/2002	Composite	Selenium	2.2U	2.2U	3 4
BP-06-2-S0X-W-C-F	8/20/2002	Composite	Selenium	2.2U	7.3	4.6
BP-06-4-S0X-W-C-F	8/22/2002	Composite	Selenium	2.2U	2.2U	3.9
BP-07-2-S0X-W-C-F	8/27/2002	Composite	Selenium	2.2U	2.9	3.7
BP-07-4-SX-W-C-F	8/29/2002	Composite	Selenium	14.5	4.0	4.1
BP-08-3-SX-W-C-F	9/4/2002	Composite	Selenium	2.2U	3.5	3.2

[1] - For the influent sample, X in the sample number = 1; for the effluent sample, X=2
µg/L - Micrograms per liter U - Non-detect

Table B-2. Data Used to Evaluate Project Objectives for the Active Lime Treatment System, Biphasic Operations (continued)

Sample Number[1]	Sample Date	Composite or Grab?	Analyte	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	4-Day Average Effluent Concentration (µg/L)
3-BP-08-2-S0X-W-C-F	8/12/2003	Composite	Zinc	1,420	10.4	
BP-01-4-S0X-W-C-F	7/18/2002	Composite	Zinc	1,320	8.3	
BP-02-2-S0X-W-C-F	7/23/2002	Composite	Zinc	1,280	25.1	
BP-02-4-S0X-W-C-F	7/25/2002	Composite	Zinc	1,250	9.7	
BP-03-2-S0X-W-C-F	7/30/2002	Composite	Zinc	1,370	16.8	15.0
BP-04-4-S0X-W-C-F	8/8/2002	Composite	Zinc	1,370	11.8	15.9
BP-05-2-SX-W-C-F	8/13/2002	Composite	Zinc	1,440	25.4	15.9
BP-05-4-S0X-W-C-F	8/15/2002	Composite	Zinc	1,520	17.6	17.9
BP-06-2-S0X-W-C-F	8/20/2002	Composite	Zinc	1,500	15.2	17.5
BP-06-4-S0X-W-C-F	8/22/2002	Composite	Zinc	1,650	38.4	24.2
BP-07-2-S0X-W-C-F	8/27/2002	Composite	Zinc	1,410	19.4	22 7
BP-07-4-SX-W-C-F	8/29/2002	Composite	Zinc	1,760	21.5	23.6
BP-08-3-SX-W-C-F	9/4/2002	Composite	Zinc	1,810	30.7	27.5

[1] - For the influent sample, X in the sample number = 1; for the effluent sample, X=2
µg/L - Micrograms per liter

Table B-3. Data Used to Evaluate Project Objectives for the Semi-Passive Alkaline Lagoon Lime Treatment System

Sample Number[1]	Sample Date	Composite or Grab?	Analyte	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	4-Day Average Effluent Concentration (µg/L)
AL-01-4-S0X-W-C-F	7/18/2002	Composite	Aluminum	32,200	639	
AL-02-2-S0X-W-C-F	7/23/2002	Composite	Aluminum	31,700	160	
AL-02-4-S0X-W-C-F	7/25/2002	Composite	Aluminum	31,900	177	
AL-03-2-S0X-W-C-F	7/30/2002	Composite	Aluminum	33,600	254	308
AL-03-4-S0X-W-C-F	8/1/2002	Composite	Aluminum	31,400	219	203
AL-04-2-S0X-W-C-F	8/6/2002	Composite	Aluminum	31,600	210	215
AL-05-2-SXW-C-F	8/13/2002	Composite	Aluminum	32,600	160	211
AL-04-4-S0X-W-C-F	8/8/2002	Composite	Aluminum	30,900	185	194
AL-01-4-S0X-W-C-F	7/18/2002	Composite	Arsenic	545	12.9	
AL-02-2-S0X-W-C-F	7/23/2002	Composite	Arsenic	526	5.1	
AL-02-4-S0X-W-C-F	7/25/2002	Composite	Arsenic	485	3.8	
AL-03-2-S0X-W-C-F	7/30/2002	Composite	Arsenic	510	5.8	6.9
AL-03-4-S0X-W-C-F	8/1/2002	Composite	Arsenic	495	6.7	5.4
AL-04-2-S0X-W-C-F	8/6/2002	Composite	Arsenic	533	3.2	4.9
AL-04-4-S0X-W-C-F	8/8/2002	Composite	Arsenic	544	2.6	4.6
AL-05-2-SX-W-C-F	8/13/2002	Composite	Arsenic	516	6.6	4.8
AL-01-4-S0X-W-C-F	7/18/2002	Composite	Cadmium	0.3U	0.7	
AL-02-2-S0X-W-C-F	7/23/2002	Composite	Cadmium	0.3U	0.3U	
AL-02-4-S0X-W-C-F	7/25/2002	Composite	Cadmium	0.3U	0.5	
AL-03-2-S0X-W-C-F	7/30/2002	Composite	Cadmium	0.3U	0.3U	0.4
AL-03-4-S0X-W-C-F	8/1/2002	Composite	Cadmium	0.3U	0.4	0.4
AL-04-2-S0X-W-C-F	8/6/2002	Composite	Cadmium	0.3U	0.3U	0.4
AL-04-4-S0X-W-C-F	8/8/2002	Composite	Cadmium	0.3U	0.3	0.3
AL-05-2-SX-W-C-F	8/13/2002	Composite	Cadmium	0.29U	0.3U	0.3
AL-01-4-S0X-W-C-F	7/18/2002	Composite	Chromium	23.5	3.8	
AL-02-2-S0X-W-C-F	7/23/2002	Composite	Chromium	19.5	1.5	
AL-02-4-S0X-W-C-F	7/25/2002	Composite	Chromium	19.5	1.9	
AL-03-2-S0X-W-C-F	7/30/2002	Composite	Chromium	19.5	3.3	2.6
AL-03-4-S0X-W-C-F	8/1/2002	Composite	Chromium	18.7	2.0	2.2
AL-04-2-S0X-W-C-F	8/6/2002	Composite	Chromium	18.9	1.6	2.2
AL-04-4-S0X-W-C-F	8/8/2002	Composite	Chromium	18.3	2.5	2.4
AL-05-2-SX-W-C-F	8/13/2002	Composite	Chromium	16.2	1.4	1.9
AL-01-4-S0X-W-C-F	7/18/2002	Composite	Copper	11.5	7.7	
AL-02-2-S0X-W-C-F	7/23/2002	Composite	Copper	9.2	3.1	
AL-02-4-S0X-W-C-F	7/25/2002	Composite	Copper	13.1	4.3	
AL-03-2-S0X-W-C-F	7/30/2002	Composite	Copper	14.0	3.6	4.7
AL-03-4-S0X-W-C-F	8/1/2002	Composite	Copper	11.9	8.6	4.9
AL-04-2-S0X-W-C-F	8/6/2002	Composite	Copper	16.1	4.1	5.2
AL-04-4-S0X-W-C-F	8/8/2002	Composite	Copper	15.8	6.2	5.6
AL-05-2-SX-W-C-F	8/13/2002	Composite	Copper	16.3	6.1	6.3

[1] - For the influent sample, X in the sample number = 1; for the effluent sample, X=2
µg/L - Micrograms per liter U - Non-detect

Table B-3. Data Used to Evaluate Project Objectives for the Semi-Passive Alkaline Lagoon Lime Treatment System (continued)

Sample Number[1]	Sample Date	Composite or Grab?	Analyte	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	4-Day Average Effluent Concentration (µg/L)
AL-01-4-S0X-W-C-F	7/18/2002	Composite	Iron	373,000	241	
AL-02-2-S0X-W-C-F	7/23/2002	Composite	Iron	365,000	24.2	
AL-02-4-S0X-W-C-F	7/25/2002	Composite	Iron	375,000	1.9U	
AL-03-2-S0X-W-C-F	7/30/2002	Composite	Iron	394,000	463	183
AL-03-4-S0X-W-C-F	8/1/2002	Composite	Iron	425,000	27.7	129
AL-04-2-S0X-W-C-F	8/6/2002	Composite	Iron	378,000	320	203
AL-04-4-S0X-W-C-F	8/8/2002	Composite	Iron	460,000	17.2	183
AL-05-2-SX-W-C-F	8/13/2002	Composite	Iron	360,000	88.1	1.5
AL-01-4-S0X-W-C-F	7/18/2002	Composite	Lead	5.7	1.2U	
AL-02-2-S0X-W-C-F	7/23/2002	Composite	Lead	2.7	1.2U	
AL-02-4-S0X-W-C-F	7/25/2002	Composite	Lead	3.9	1.2U	
AL-03-2-S0X-W-C-F	7/30/2002	Composite	Lead	5.1	1.2U	1.2
AL-03-4-S0X-W-C-F	8/1/2002	Composite	Lead	6.3	2.6	1.6
AL-04-2-S0X-W-C-F	8/6/2002	Composite	Lead	5.7	1.2U	1.6
AL-04-4-S0X-W-C-F	8/8/2002	Composite	Lead	5.3	3.3	2.1
AL-05-2-SX-W-C-F	8/13/2002	Composite	Lead	5.7	1.4U	2.1
AL-01-4-S0X-W-C-F	7/18/2002	Composite	Nickel	1,690	47.2	
AL-02-2-S0X-W-C-F	7/23/2002	Composite	Nickel	1,680	15.7	
AL-02-4-S0X-W-C-F	7/25/2002	Composite	Nickel	1,580	14.2	
AL-03-2-S0X-W-C-F	7/30/2002	Composite	Nickel	1,670	22.4	24.9
AL-03-4-S0X-W-C-F	8/1/2002	Composite	Nickel	1,570	20.1	18.1
AL-04-2-S0X-W-C-F	8/6/2002	Composite	Nickel	1,610	20.4	19.3
AL-04-4-S0X-W-C-F	8/8/2002	Composite	Nickel	1,650	20.4	20.8
AL-05-2-SX-W-C-F	8/13/2002	Composite	Nickel	1,600	20.4	20.3
AL-01-4-S0X-W-C-F	7/18/2002	Composite	Selenium	4.0	2.5U	
AL-02-2-S0X-W-C-F	7/23/2002	Composite	Selenium	7.0	2.5U	
AL-02-4-S0X-W-C-F	7/25/2002	Composite	Selenium	3.4	3.5	
AL-03-2-S0X-W-C-F	7/30/2002	Composite	Selenium	2.5	2.5U	2.8
AL-03-4-S0X-W-C-F	8/1/2002	Composite	Selenium	2.5	2.5U	2.8
AL-04-2-S0X-W-C-F	8/6/2002	Composite	Selenium	2.5	2.5U	2.8
AL-04-4-S0X-W-C-F	8/8/2002	Composite	Selenium	2.5	6.3	3.5
AL-05-2-SX-W-C-F	8/13/2002	Composite	Selenium	2.2	3.6	3.7
AL-01-4-S0X-W-C-F	7/18/2002	Composite	Zinc	353.0	13.7	
AL-02-2-S0X-W-C-F	7/23/2002	Composite	Zinc	352.0	10.3	
AL-02-4-S0X-W-C-F	7/25/2002	Composite	Zinc	350.0	6.2	
AL-03-2-S0X-W-C-F	7/30/2002	Composite	Zinc	360 0	9.6	10.0
AL-03-4-S0X-W-C-F	8/1/2002	Composite	Zinc	351.0	12.2	9.6
AL-04-2-S0X-W-C-F	8/6/2002	Composite	Zinc	369.0	19.0	11.8
AL-04-4-S0X-W-C-F	8/8/2002	Composite	Zinc	361.0	9.3	12.5
AL-05-2-SX-W-C-F	8/13/2002	Composite	Zinc	353.0	33.2	18.4

[1] - For the influent sample, X in the sample number = 1; for the effluent sample, X=2
µg/L - Micrograms per liter U - Non-detect

Table B-4. Statistical Summary of Active Lime Treatment System, Monophasic Operations Data

Analyte	Minimum Concentration (µg/L)	Maximum Concentration (µg/L)	Mean Concentration (µg/L)	Median Concentration (µg/L)	Standard Deviation	Coefficient of Variation (%)
Influent						
Aluminum	98,600	119,000	107,800	107,000	6,734	6
Arsenic	2,810	3,470	3,235	3,310	252	8
Cadmium	13.2	46.3	26.1	22.6	14 1	54
Chromium	266	629	341	293	128	38
Copper	434	549	502	526	46.4	9
Iron	392,000	545,000	456,428	456,000	49 429	11
Lead	2.3	10.0	7 1	8.5	3.0	43
Nickel	2,410	2,760	2,560	2,500	128	5
Selenium	20.0	32.3	27.1	28 0	5.3	19
Zinc	490	583	538	536	28 9	5
Effluent						
Aluminum	103	1,090	633	584	284	45
Arsenic	1.8	10.8	6.27	7.10	3.52	56
Cadmium	U	U	NA	NA	NA	NA
Chromium	0.67	11.6	3.04	1.70	3 82	126
Copper	1.9	5.4	3.07	2.10	1 50	49
Iron	5.7	350	176	129	130	74
Lead	0.9	4.5	1.56	0.90	1 32	85
Nickel	17.3	113	46.8	41.8	34.7	74
Selenium	1.8	2.6	2.14	1.80	0.428	20
Zinc	2.6	12 1	5.61	3.50	3.62	65
4-Day Average Effluent						
Aluminum	466	765	579	542	136	24
Arsenic	4.5	8.9	6.69	6.68	2 02	30
Cadmium	U	U	NA	NA	NA	NA
Chromium	1.4	3.9	2.66	2.69	1.34	50
Copper	2.0	3.3	2.54	2.49	0.543	21
Iron	136	250	202	211	49.8	25
Lead	0.9	1.8	1.22	1.09	0.401	33
Nickel	31.7	67.7	53.9	58.2	15.6	29
Selenium	1 8	2.2	2 00	2.00	0 163	8
Zinc	4.0	6.5	5 01	4.78	1 15	23

% - Percent µg/L - Micrograms per liter NA - Not applicable
U - Not detected (all effluent samples were non-detect for cadmium)

Table B-5. Statistical Summary of Active Lime Treatment System, Biphasic Operations Data

Analyte	Minimum Concentration (µg/L)	Maximum Concentration (µg/L)	Mean Concentration (µg/L)	Median Concentration (µg/L)	Standard Deviation	Coefficient of Variation (%)
Influent						
Aluminum	326,000	486,000	381,000	361,000	48,792	13
Arsenic	1,330	4,050	2,239	1,970	866	39
Cadmium	47.9	68.3	54	52	6.1	11
Chromium	729	1,240	877	807	173	20
Copper	2,110	2,990	2,383	2,300	275	12
Iron	336,000	653,000	461,615	435,000	100,251	22
Lead	1.7	12.2	8.2	8.5	3.1	38
Nickel	5,980	8,770	7,024	6,720	833	12
Selenium	4.6	14.5	8.8	8.0	4.6	53
Zinc	1,250	1,810	1,469	1,420	175	12
Effluent						
Aluminum	183	2,860	1,118	1,040	782	70
Arsenic	4.8	11.8	8 59	8.50	1.88	22
Cadmium	0 3	1.3	0.71	0.78	0.304	43
Chromium	1.4	46.3	5.70	2.40	12.2	214
Copper	3.7	12.8	8.05	8.50	2.50	31
Iron	1.9	243	44.9	30.5	66.2	147
Lead	1.2	4.4	2.00	1.40	1.09	55
Nickel	7.1	55.3	34.2	38.9	15.4	45
Selenium	2.2	7.3	3.78	3.70	1.47	39
Zinc	8.3	38.4	19.3	17.6	8.87	46
4-Day Average Effluent						
Aluminum	396	1,820	971	869	481	50
Arsenic	8.0	9.8	8.82	8.80	0.760	9
Cadmium	0.6	1.0	0.77	0.78	0.162	21
Chromium	1.9	13.4	7 11	2.38	5.86	83
Copper	6.7	9.6	8.41	8.38	0.957	11
Iron	11.7	94.3	52.4	47.0	31.3	60
Lead	1.5	2 4	1.84	1.88	0.284	15
Nickel	19.4	49.8	35.5	37.4	12.2	34
Selenium	3.2	4.6	3.90	3.88	0.447	11
Zinc	15.0	27.5	20.0	17.9	4.52	23

% - Percent µg/L - Micrograms per liter

Table B-6. Statistical Summary of Alkaline Lagoon Lime Treatment System Data

Analyte	Minimum Concentration (µg/L)	Maximum Concentration (µg/L)	Mean Concentration (µg/L)	Median Concentration (µg/L)	Standard Deviation	Coefficient of Variation (%)
Influent						
Aluminum	30,900	33,600	31,988	31,800	827	3
Arsenic	485	545	519	521	21.9	4
Cadmium	U	U	NA	NA	NA	NA
Chromium	16.2	23.5	19.3	19.2	2.0	10
Copper	9.2	16.3	13.5	13.6	2.5	19
Iron	360,000	460,000	391,250	376,500	34,458	9
Lead	2.7	6.3	5.1	5.5	1.2	24
Nickel	1,570	1,690	1,631	1,630	47.0	3
Selenium	2.2	7.0	3.3	2.5	1.6	48
Zinc	350	369	356	353	6.5	2
Effluent						
Aluminum	160	639	251	198	160	64
Arsenic	2.6	12.9	5.84	5.45	3.24	55
Cadmium	0.3	0.7	0.38	0.33	0.131	34
Chromium	1.4	3.8	2.25	1.95	0.883	39
Copper	3.1	8.6	5.46	5.2	2.00	37
Iron	1.9	463	148	57.9	173	117
Lead	1.2	3.3	1.66	1.20	0.819	49
Nickel	14.2	47.2	22.6	20.4	10.3	46
Selenium	2.5	6.3	3.24	2.50	1.33	41
Zinc	6.2	33.2	14.2	11.3	8.56	60
4-Day Average Effluent						
Aluminum	194	308	226	211	46.4	21
Arsenic	4.6	6.9	5.30	4.88	0.941	18
Cadmium	0.3	0.4	0.36	0.37	0.049	14
Chromium	1.9	2.6	2.25	2.20	0.274	12
Copper	4.7	6.3	5.32	5.15	0.628	12
Iron	1.5	203	140	183	82.1	59
Lead	1.2	2.1	1.70	1.55	0.393	23
Nickel	18.1	24.9	20.7	20.3	2.57	12
Selenium	2.8	3.7	3.09	2.75	0.469	15
Zinc	9.6	18.4	12.5	11.8	3.56	29

% - Percent µg/L - Microgram per liter NA - Not applicable
U - Not detected (all influent samples were non-detect for cadmium)

APPENDIX C
DETAILED COST ELEMENT SPREADSHEETS

Table C-1. Cost Element Details for the Active Lime Treatment System - Monophasic Operation

	Description	Quantity	Unit	Unit cost	Subtotal
I	**Site Preparation**				
	Design (20% of capital cost)	1	lump sum	$140,884.83	$140,884.83
	Construction Management (15% of capital cost)	1	lump sum	$105,663 62	$105,663.62
	Project Management (10% of capital cost)	1	lump sum	$70,442.41	$70,442.41
	Subtotal				**$316,990.86**
II	**Permitting and Regulatory Requirements**				
	Superfund Site, No Permitting Costs				$0.00
	Subtotal				**$0.00**
III	**Capital and Equipment**				**$704,424.14**
1	**Conventional Lime Treatment System**				
a	***Phase 1 Reaction Module:***	1	lump sum	**$93,361.44**	**$93,361.44**
	10,000-Gallon Fiberglass Reinforced Polyethylene Tank, Mixer and Mixer Bridge, pH Probe and Controller, Lime Injection Pump, Local Control Panel, and Electrical Controls and Wiring				
b	***Phase 2 Reaction Module:***	1	lump sum	**$102,611.28**	**$102,611.28**
	10,000-Gallon Fiberglass Reinforced Polyethylene Tank, Mixer and Mixer Bridge, pH Probe and Controller, Lime Injection Pump, Local Control Panel, and Electrical Controls and Wiring				
c	***Phase 2 Clarifier Module:***	1	lump sum	**$125,267.24**	**$125,267.24**
	Lamella Type Clarifier with Removable Plates, Flash Mix Tank, Flash Mixer, Flocculation Mixer, Variable Speed Controller for Flocculation Mixer, Local Control Panel, Polymer Dosing System, Solids Recycle Pump with Timer, Solids Transfer Pump with Timer, and Electrical Controls and Wiring				
d	***Phase 2 Solids Separation:***	1	lump sum	**$116,662.36**	**$116,662.36**
	(2) 10,000-Gallon, Polyethylene Tanks with Cone Bottoms, Domed Tops, Epoxy Coated Steel Legs, 20-Cubic Foot Capacity Filter Press with Gasketed Recessed Chamber Plates, Set of Clothes, Skid-Mounted Air Diaphragm Feed Pumps, Air Blow Down Manifold, (3) Pump Repair Kits, and Spare Pump				
e	***Lime Slurry Equipment:***	1	lump sum	**$19,394.04**	**$19,394.04**
	8,000-Gallon Fiberglass Reinforced Polyethylene Tank with Cone Bottom, Open Top, Access Ladder with Safety Cage, Mixer and Mixer Bridge, Lime Slurry Mixer, and Electrical Controls with Wiring				
f	***Utility water storage/Delivery:***	1	lump sum	**$87,966.28**	**$87,966.28**
	(3) 15,000-Gallon Fiberglass Reinforced Polyethylene Tanks with Cone Bottom, Open Top, (1) Access Ladder with Safety Cage, and Utility Water Pump System				
g	***Fuel storage:***	1	lump sum	**$6,150.00**	**$6,150.00**
	1,000-Gallon Diesel Fuel Storage Tank				
h	***System Assembly***	1	lump sum	**$116,940.00**	**$116,940.00**
	Subtotal				**$668,352.64**

Table C-1. Cost Element Details for the Active Lime Treatment System - Monophasic Operation (continued)

	Description	Quantity	Unit	Unit cost	Subtotal
2	**Collection Pumping and Appurtenances**				
a	***Capture & Route Delta Seep Flows to CUD***				**$6,214.00**
	Earthwork and Sandbag Coffer Dam	20	cubic yard	$25.00	$500.00
	Purchase/Place High Density Polyethylene liner	150	square feet	$1.20	$180.00
	Berkeley 6AL3 Submersible Pump and 3 hp motor	1	each	$2,500.00	$2,500.00
	Electric and Control Cable	700	linear feet	$3.27	$2,289.00
	3-inch Diameter High Density Polyethylene Pipe	700	linear feet	$0.85	$595.00
	3-inch Diameter Check Valve	1	each	$150.00	$150.00
b	***Route Delta Seep and CUD to System***				**$9,448.00**
	Berkeley 6AL3 Submersible pump and 3 hp motor	1	cubic yard	$2,500.00	$2,500.00
	Electric and Control Cable	1,650	linear feet	$3.27	$5,395.50
	3-inch Diameter High Density Polyethylene Pipe	1,650	linear feet	$0 85	$1,402.50
	3-inch Diameter Check Valve	1	each	$150.00	$150.00
c	***Route ADIT/PUD flows to System***				**$930.00**
	4-inch Diameter High Density Polyethylene pipe	500	linear feet	$1.56	$780.00
	4-inch Diameter Check Valve	1	each	$150.00	$150.00
	Subtotal				**$16,592.00**
3	**Automation**				
a	***Remote Monitoring/Alarm System***				**$9,742.50**
	Sensaphone SCADA 3000 (control system, logger, alarm)	1	lump sum	$2,495.00	$2,495.00
	Miscellaneous Accessories for SCADA 3000	1	lump sum	$500.00	$500.00
	Personal Computer	1	lump sum	$2,000.00	$2,000.00
	Professional Series 900 MHz Data Transceivers	1	lump sum	$1,000.00	$1,000.00
	Miscellaneous Accessories for Transceivers	1	lump sum	$500.00	$500.00
	Installation Cost (assumes 50% of equipment cost)	1	lump sum	$3,247.50	$3,247.50
b	***pH Controller System***				**$8,242.00**
	Pulse Output Controller	2	each	$1,160.00	$2,320.00
	Electronic Diaphragm Pumps	4	each	$826.00	$3,304.00
	pH Probe	4	each	$175.00	$700.00
	pH Cable	2	each	$45 00	$90.00
	Temperature Sensor	2	each	$155.00	$310.00
	Temperature Cable	2	each	$45.00	$90.00
	Accessories (cables, calibration solution)	1	lump sum	$150.00	$150.00
	Installation Cost (assumes 50% of equipment cost)	1	lump sum	$1,278.00	$1,278.00
	Subtotal				**$17,984.50**
4	**Communications**				
	Motorola 9505 Satellite Phone	1	lump sum	$1,495.00	$1,495.00
	Subtotal				**$1,495.00**
	Total Fixed Cost				**$1,021,415.00**

Table C-1. Cost Element Details for the Active Lime Treatment System - Monophasic Operation (continued)

	Description	Quantity	Unit	Unit cost	Subtotal
IV	**System Start up and Shakedown**				
	System Assembly	160	hour	$56.19	$8,990.40
	Start-up and Shake Down Labor	160	hour	$56.19	$8,990 40
	Subtotal				**$17,980.80**
V	**Consumables and Rentals**				
	Lime Consumption (dry weight)	13.6	ton	$366.00	$4,977.60
	Polymer	143	gallon	$13.64	$1,950.52
	Personal Protective Equipment	145	each	$7.00	$1,015.00
	Compressor	2	month	$2,400.00	$4,800.00
	Heavy Equipment Rental Including Fuel	2	month	$4,000.00	$8,000.00
	Field Trailer	2.5	month	$700.00	$1,750.00
	Storage Connex	60	month	$325.00	$19,500.00
	Subtotal				**$41,993.12**
VI	**Labor**				
	Field Technicians	695	hour	$56.19	$39,052.05
	Administrative Support	42.3	hour	$61.16	$2,587.07
	Project Management	104	hour	$90.00	$9,360.00
	Engineering	145	hour	$100.00	$14,500.00
	Program Administrator	82	hour	$100.00	$8,200.00
	Subtotal				**$73,699.12**
VII	**Utilities**				
	Generator (125 Kilowatt)	2	month	$3,400.00	$6,800.00
	Backup Generator (125 Kilowatt)	2	month	$3,400.00	$6,800.00
	Generator Fuel	4,630	gallon	$1.40	$6,482.00
	SCADA communication service	2	month	$75.00	$150.00
	Satellite Phone Communications	2	month	$50.00	$100.00
	Portable Toilets	2	month	$325.00	$650 00
	Subtotal				**$20,982.00**
VIII	**Residual Waste Shipping, Handling and Disposal**				
	Off-Site Hazardous Sludge Disposal (wet weight)	62	ton	$263.00	$16,306.00
	Subtotal				**$16,306.00**
IX	**Analytical Services**				
	Total Metals (Effluent Discharge)	35	each	$80.00	$2,800.00
	Total and Leachable Metals (Waste Characterization)	1	each	$280.00	$280.00
	Subtotal				**$3,080.00**
X	**Maintenance and Modifications**				
	Major Equipment Replacement	2	month	$4,000.00	$8,000.00
	Subtotal				**$8,000.00**
XI	**Demobilization**				
	System Winterization Labor	320	hour	$56.19	$17,980.80
	Subtotal				**$17,980.80**
	Total Variable Cost				**$200,021.84**

Table C-1. Cost Element Details for the Active Lime Treatment System - Monophasic Operation (continued)

	Description	Total
	Total 1st Year Cost	**$1,221,436.84**
	Total 1st Year Cost/1000-Liters	**$128.05**
	Total Variable Cost/1000-Liters	**$20.97**
	Cumulative 5-Year Total Variable Cost (Present Worth at 7 Percent Rate of Return)	**$820,129.00**
	Cumulative 10-Year Total Variable Cost (Present Worth at 7 Percent Rate of Return)	**$1,404,871.00**
	Cumulative 15-Year Total Variable Cost (Present Worth at 7 Percent Rate of Return)	**$1,821,783.00**

% - Percent
CUD – Channel under drain
hp - Horsepower
MHz - MegaHertz
PUD – Pit under drain
SCADA - Supervisory Control and Data Acquisition

Table C-2. Cost Element Details for the Active Lime Treatment System - Biphasic Operation

	Description	Quantity	Unit	Unit cost	Subtotal
I	**Site Preparation**				
	Design (20% of capital cost)	1	lump sum	$172,969.44	$172,969.44
	Construction Management (15% of capital cost)	1	lump sum	$129,727.08	$129,727.08
	Project Management (10% of capital cost)	1	lump sum	$86,484.72	$86,484.72
	Subtotal				**$389,181.24**
II	**Permitting and Regulatory**				
	Superfund Site, No Permitting Costs				$0.00
	Subtotal				**$0.00**
III	**Capital and Equipment**				**$864,847.22**
1	**Conventional Lime Treatment System**				
a	***Phase 1 Reaction Module:***	1	lump sum	$93,361.44	**$93,361.44**
	10,000-Gallon Fiberglass Reinforced Polyethylene Tank, Mixer and Mixer Bridge, pH Probe and Controller, Lime Injection Pump, Local Control Panel, and Electrical Controls and Wiring				
b	***Phase 1 Clarifier Module:***	1	lump sum	$149,133.08	**$149,133.08**
	Lamella Type Clarifier with Removable Plates, Flash Mix Tank, Flash Mixer, Flocculation Mixer, Variable Speed Controller for Flocculation Mixer, Local Control Panel, Polymer Dosing System, Solids Transfer Pump with Timer, Electrical Controls and Wiring, Spare Gaskets and Plates				
c	***Phase 1 Solids Separation:***	1	lump sum	$116,662.36	**$116,662.36**
	(2) 10,000-Gallon, Polyethylene Tanks with Cone Bottoms, Domed Tops, Epoxy Coated Steel Legs, 20-Cubic Foot Capacity Filter Press with Gasketed Recessed Chamber Plates, Set of Clothes, Skid-Mounted Air Diaphragm Feed Pumps, Air Blow Down Manifold, (3) Pump Repair Kits, and Spare Pump				
d	***Phase 2 Reaction Module:***	1	lump sum	$102,611.28	**$102,611.28**
	10,000-Gallon Fiberglass Reinforced Polyethylene Tank, Mixer and Mixer Bridge, pH Probe and Controller, Lime Injection Pump, Local Control Panel, and Electrical Controls and Wiring				
e	***Phase 2 Clarifier Module:***	1	lump sum	$125,267.24	**$125,267.24**
	Lamella Type Clarifier with Removable Plates, Flash Mix Tank, Flash Mixer, Flocculation Mixer, Variable Speed Controller for Flocculation Mixer, Local Control Panel, Polymer Dosing System, Solids Recycle Pump with Timer, Solids Transfer Pump with Timer, and Electrical Controls and Wiring				
f	***Lime Slurry Equipment:***	1	lump sum	$19,394.04	**$19,394.04**
	8,000-Gallon Fiberglass Reinforced Polyethylene Tank with Cone Bottom, Open Top, Access Ladder with Safety Cage, Mixer and Mixer Bridge, Lime Slurry Mixer, and Electrical Controls with Wiring				
g	***Utility Storage/Delivery:***	1	lump sum	$87,966.28	**$87,966.28**
	(3) 15,000-Gallon Fiberglass Reinforced Polyethylene Tanks with Cone Bottom, Open Top, (1) Access Ladder with Safety Cage, and Utility Water Pump System				
h	***Fuel Storage:***	1	lump sum	$6,150.00	**$6,150.00**
	1,000-Gallon Diesel Fuel Storage Tank				
i	***System Assembly***	1	lump sum	$116,940.00	**$116,940.00**
	Subtotal				**$817,485.72**

Table C-2. Cost Element Details for the Active Lime Treatment System - Biphasic Operation (continued)

	Description	Quantity	Unit	Unit cost	Subtotal
2	**Collection Pumping and Appurtenances**				
a	***Route Pond Water to System***				**$930.00**
	4-inch Diameter High Density Polyethylene pipe	500	linear feet	$1.56	$780.00
	4-inch Diameter Check Valve	1	each	$150.00	$150.00
b	***Route Phase II Clarifier to Pit Clarifier***				**$26,952.00**
	Submersible Pump	2	each	$12,000.00	$24,000.00
	4-inch Diameter High Density Polyethylene pipe	1,700	linear feet	$1.56	$2,652.00
	4-inch Diameter Check Valve	2	each	$150.00	$300.00
	Subtotal				**$27,882.00**
3	**Automation**				
a	***Remote Monitoring/Alarm System***				**$9,742.50**
	Sensaphone SCADA 3000 (control system, logger, alarm)	1	lump sum	$2,495.00	$2,495.00
	Miscellaneous Accessories for SCADA 3000	1	lump sum	$500.00	$500.00
	Personal Computer	1	lump sum	$2,000.00	$2,000.00
	Professional Series 900 MHz Data Transceivers	1	lump sum	$1,000.00	$1,000.00
	Miscellaneous Accessories for Transceivers	1	lump sum	$500.00	$500.00
	Installation Cost (assumes 50% of equipment cost)	1	lump sum	$3,247.50	$3,247 50
b	***pH Controller System***				**$8,242.00**
	Pulse Output Controller	2	each	$1,160.00	$2,320.00
	Electronic Diaphragm Pumps	4	each	$826.00	$3,304.00
	pH Probe	4	each	$175.00	$700.00
	pH Cable	2	each	$45.00	$90.00
	Temperature Sensor	2	each	$155.00	$310.00
	Temperature Cable	2	each	$45.00	$90.00
	Accessories (cables, calibration solution)	1	lump sum	$150.00	$150.00
	Installation Cost (assumes 50% of equipment cost)	1	lump sum	$1,278.00	$1,278.00
	Subtotal				**$17,984.50**
4	**Communications**				
	Motorola 9505 Satellite Phone	1	lump sum	$1,495.00	$1,495.00
	Subtotal				**$1,495.00**
	Total Fixed Cost				**$1,254,028.46**

Table C-2. Cost Element Details for the Active Lime Treatment System - Biphasic Operation (continued)

	Description	Quantity	Unit	Unit cost	Subtotal
IV	**System Start-up and Shakedown**				
	System Assembly	160	hour	$70.00	$11,200.00
	Start up and Shakedown Labor	160	hour	$70.00	$11,200.00
	Subtotal				**$22,400.00**
V	**Consumables and Rentals**				
	Fuel	320	gallon	$2.39	$764.80
	Lime (dry weight)	49 6	ton	$340.00	$16,864.00
	Polymer	275	gallon	$13.64	$3,751.00
	Personal Protective Equipment	1	lump sum	$330.00	$330.00
	Compressor	2	month	$2,400 00	$4,800.00
	Heavy Equipment Rental Including Fuel	2	month	$4,000.00	$8,000.00
	Field Trailer	2	month	$800.00	$1,600.00
	Storage Connex	60	month	$325.00	$19,500.00
	Subtotal				**$55,609.80**
VI	**Labor**				
	Field Technicians	470	hour	$70.00	$32,900.00
	Administrative Support	40	hour	$45.00	$1,800.00
	Project Management	104	hour	$90.00	$9,360.00
	Engineering	145	hour	$100 00	$14,500.00
	Program Administrator	82	hour	$100.00	$8,200.00
	Subtotal				**$66,760.00**
VII	**Utilities**				
	Generator (125 Kilowatt)	2	month	$3,400.00	$6,800.00
	Backup Generator (125 Kilowatt)	2	month	$3,400.00	$6,800.00
	Generator Fuel	2,117	gallon	$1.40	$2,963.80
	SCADA communication service	1	month	$75 00	$75.00
	Satellite Phone Communications	2	month	$50.00	$100.00
	Portable Toilets	2	month	$325.00	$650.00
	Subtotal				**$17,388.80**
VIII	**Residual Waste Shipping, Handling and Disposal**				
	Off-site Hazardous Sludge Disposal (wet weight)	41.1	ton	$250.00	$10,275.00
	Pit Clarifier Clean Out	0.33	lump sum	$30,000.00	$9,900.00
	Subtotal				**$20,175.00**
IX	**Analytical Services**				
	Total Metals (Effluent Discharge)	19	each	$80.00	$1,520.00
	Total and Leachable Metals (Waste Characterization)	2	each	$280.00	$560.00
	Subtotal				**$2,080.00**
X	**Maintenance and Modifications**				
	Major Equipment Replacement	1	lump sum	$18,000.00	$18,000.00
	Subtotal				**$18,000.00**
XI	**Demobilization**				
	System Winterization Labor	320	hour	$70.00	$22,400.00
	Subtotal				**$22,400.00**
	Total Variable Cost				**$224,813.60**

Table C-2. Cost Element Details for the Active Lime Treatment System - Biphasic Operation (continued)

	Description	Total
	Total 1st Year Cost	**$1,478,842.06**
	Total 1st Year Cost/1000-Liters	**$111.63**
	Total Variable Cost/1000-Liters	**$16.97**
	Cumulative 5-Year Total Variable Cost (Present Worth at 7 Percent Rate of Return)	**$921,780.00**
	Cumulative 10-Year Total Variable Cost (Present Worth at 7 Percent Rate of Return)	**$1,578,998.00**
	Cumulative 15-Year Total Variable Cost (Present Worth at 7 Percent Rate of Return)	**$2,047,585.00**

% - Percent
MHz – MegaHertz
SCADA - Supervisory Control and Data Acquisition

Table C-3. Cost Element Details for the Semi-passive Alkaline Lagoon Treatment System

	Description	Quantity	Unit	Unit cost	Subtotal
I	**Site Preparation**				
	Design (20% of Capital Cost)	1	lump sum	$37,683.05	$37,683.05
	Construction Management (15% of Capital Cost)	1	lump sum	$28,262.29	$28,262.29
	Project Management (10% of Capital Cost)	1	lump sum	$18,841.53	$18,841.53
	Survey and Drafting Services	1	lump sum	$4,025.16	$4,025 16
	Subtotal				**$88,812.03**
II	**Permitting and Regulatory Costs**				
	Superfund Site, No Permitting Costs				$0.00
	Subtotal				**$0.00**
III	**Capital and Equipment**				**$188,415.25**
1	**General Site Work**				**$98,572.51**
	Lagoon Berm Extension, General Site Grading	1	lump sum	$45,950.87	$45,950.87
	Lagoon Bottom Liner/Berm and Treatment Pad Liner	1	lump sum	$48,278.30	$48,278.30
	Lagoon Particle Settling Partitions	3	each	$1,447.78	$4,343.34
2	**Collection Systems**				**$30,776.23**
	Channel Under Drain Pump with Motor	2	each	$3,665.91	$7,331.83
	Channel Under Drain Collection Tank Level Transducer	1	each	$2,058.25	$2,058.25
	Channel Under Drain Collection Tank	1	each	$459.93	$459.93
	Channel Under Drain Magnetic Flow Meter	1	each	$3,534.98	$3,534.98
	Channel Under Drain Power and Control Wiring	1	each	$17,391.24	$17,391.24
3	**Equipment**				**$33,896.34**
	Reaction Tank	3	each	$1,968.33	$5,904.98
	Lime Slurry Tanks and Mixer Tank Motors	2	each	$6,415.02	$12,830.04
	Lime Recirculating Pump	2	each	$1,444.54	$2,889.08
	Lime Delivery Pumps/Diffusers/Aerator	2	each	$1,639.22	$3,278.44
	Rotary Vane Compressor	4	each	$789.06	$3,156.24
	Submersible Pumps	2	each	$848.80	$1,697.60
	Submersible Dewatering Pump	1	each	$1,259.60	$1,259.60
	Pacer/Honda Trash Pump and Hoses	1	each	$2,880.36	$2,880.36
4	**Electrical**				**$3,384.30**
	Variable Frequency Drive	2	each	$275.00	$550.00
	Distribution Panel	1	each	$500.00	$500.00
	5 Kilowatt Honda Gas Generator	1	each	$2,334.30	$2,334.30
5	**Miscellaneous**				**$21,785.87**
	Storage Bins Including Lock Box and Wind Tower	3	each	$2,911.82	$8,735.46
	Constant-Monitoring pH Probes	2	each	$162.00	$324.00
	Monitoring Equipment	1	lump sum	$11,231.41	$11,231.41
	Motorola 9505 Satellite Phone	1	lump sum	$1,495.00	$1,495.00
	Subtotal				**$188,415.25**
	Total Fixed Cost				**$277,227.28**

Table C-3. Cost Element Details for the Semi-passive Alkaline Lagoon Treatment System (continued)

	Description	Quantity	Unit	Unit cost	Subtotal
IV	**System Start up and Shakedown**				
	System Assembly	128	hour	$45.36	$5,806.08
	System Start up and Shakedown Labor	128	hour	$45.36	$5,806.08
	Subtotal				**$11,612.16**
V	**Consumables and Rentals**				
	Lime Consumption	19.4	ton	$366.00	$7,100.40
	Compressor	4	month	$2,400.00	$9,600.00
	Heavy Equipment Rental Including Fuel	4	month	$1,000.00	$4,000.00
	Field Trailer (Including Mobilization)	6	month	$466.67	$2,800 00
	Storage Connex (Including Mobilization)	36	month	$325.00	$11,700.00
	Solids Collection Fabric-Filter Bags	6	each	$252.52	$1,515.12
	Health and Safety Equipment Including Personal Protective Equipment	1	lump sum	$5,000.00	$5,000.00
	Subtotal				**$41,715.52**
VI	**Labor**				
	Field Technicians	1,280	hour	$45.36	$58,060.80
	Administrative Support	42	hour	$58.38	$2,451.96
	Project Management	104	hour	$90.00	$9,360.00
	Engineering	145	hour	$100.00	$14,500.00
	Program Administration	82	hour	$100.00	$8,200.00
	Subtotal				**$92,572.76**
VII	**Utilities**				
	Generator (40 Kilowatt)	4	month	$1,845.00	$7,380.00
	Backup Generator (25 Kilowatt)	4	month	$1,260.00	$5,040.00
	Diesel	1,023	gallon	$1.42	$1,452.66
	Satellite Phone Communications	2	month	$50.00	$100.00
	Portable Toilets	6	month	$325.00	$1,950.00
	Subtotal				**$15,922.66**
VIII	**Residual Waste Handling and Disposal**				
	Non-hazardous Solids Excavation and Off Site Disposal (wet weight)	63	ton	$275.00	$17,325.00
	Subtotal				**$17,325.00**
IX	**Analytical Services**				
	Total Metals (Effluent Discharge)	6	each	$80.00	$480.00
	Total and Leachable Metals (Waste Characterization)	2	each	$280.00	$560.00
	Subtotal				**$1,040.00**
X	**Maintenance and Modifications**				
	Major Equipment Replacement	1	lump sum	$5,400.00	$5,400.00
	Subtotal				**$5,400.00**
XI	**Demobilization**				
	System Winterization Labor	256	hour	$45.36	$11,612.16
	Subtotal				**$11,612.16**
	Total Variable Cost				**$197,200.26**

Table C-3. Cost Element Details for the Semi-passive Alkaline Lagoon Treatment System (continued)

	Description	Total
	Total 1st Year Cost	**$474,427.54**
	Total 1st Year Cost/1000-Liters	**$39.54**
	Total Variable Cost/1000-Liters	**$16.44**
	Cumulative 5-Year Total Variable Cost (Present Worth at 7 Percent Rate of Return)	**$808,559.00**
	Cumulative 10-Year Total Variable Cost (Present Worth at 7 Percent Rate of Return)	**$1,385,051.00**
	Cumulative 15-Year Total Variable Cost (Present Worth at 7 Percent Rate of Return)	**$1,796,081.00**

% - Percent