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BESCORP Soil Washing System for Lead Battery Site Treatment

Applications Analysis Report

Risk Reduction Engineering Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

Notice

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Foreword

The Superfund Innovative Technology Evaluation (SITE) Program was authorized in the 1966 Superfund Amendments. The Program is a joint effort between EPA's Office of Research and Development and Office of Sdid Waste and Emergency Response. The purpose of the program Is to enhance the development of hazardous waste treatment technologies necessary for implementing new cleanup standards that require greater reliance on permanent remedies. This Is accomplished by performing the techndogy demonstrations designed to provide engineering and economic data on selected technologies.

This project consists of an evaluation of the BESCORP Soil Washing System (BSWS). The Demonstration Test took place at the Alaskan Battery Enterprises (ABE) Site in Fairbanks, Alaska. The primary technical objective of this project was to determine the ability of the process to produce washed soil that would comply with EPA's lead cleanup goals for redeposit at the site (less than 1,000 mg/kg total lead and less than 5 mg/L TCLP lead). The goals of the study were (1) to evaluate the technical effectiveness and economics of this technology relative to its ability to treat soils contaminated with lead, lead compounds, and battery casing chips from broken lead batteries; and (2) to establish the potential applicability of the process to other wastes and Superfund sites. The results are summarized in this Applications Analysis Report.

Additional copies of this report may be obtained at no charge from EPA's Center for Environmental Research Information, 26 West Martin Luther King Drive, Cincinnati, Ohio, 45266, using the EPA document number found on the report's front cover. Once this supply is exhausted, copies can be purchased from the National Technical Information Service, Ravensworth Building, Springfield, Virginia, 22161, (703) 487-4600. Reference copies will be available at EPA libraries in their Hazardous Waste Collection.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

Abstract

Thls report evaluates the Brice Environmental Services Corporation (BESCORP) Soil Washing System (BSWS) and its applicability in remediating lead-contaminated soil at lead battery sites. It presents performance and economic data, developed from the U.S. Environmental Protection Agency Superfund Innovative Technology Evaluation (SITE) Demonstration (three test runs) and additional data provided by the developer. The Demonstration took place at the Alaskan Battery Enterprises (ABE) Site In Fairbanks, Alaska.

The original BSWS, built to process 20 tons per hour (tph) of soil when removing silt and clay from uncontaminated sandy soil, was a water-based, volume-reduction unit that employed agitation, attrition scrubbing, high pressure washing, and particle size separation. This system was modified to remove lead, lead compounds, and battery casing chips through the addition of a density separator and a casing chip separator. The modified system capacity is about 5 tph, primarily due to restricted flow In the casing chip separator.

Products from the process included washed gravel and sand, a metallic-lead fraction, battery casing chips. a water effluent suitable for discharge to a POTW, and a lead-contamlnated sludge effluent for RCRA disposal or posttreatment. The metallic lead and casing chips were potentially recyclable to lead smelters. However, this is not a current industry practice.

The system, operating from 2 to 4 tph, generated a washed gravel product, free of fine material, that passed EPA's redeposit cleanup goals for total lead (less than l.000 mg/kg) and TCLP lead (less than 5 mg/L). The washed sand did not achieve the cleanup goals due to the presence of contaminated fines that the system did not separate from the sand fraction. BESCORP did not anticipate this result during the Demonstration because the feed soil differed significantly from the soil samples tested In the pre-Demonstration treatability study.

Economic data for a commercial 20-tph unit processing wastes similar to those treated in the SITE Demonstration, including disposal of waste effluents, project operating costs to be about $165/ton of soil (dry basis) containing 6.6 wt percent moisture. This figure does not reflect any revenue from recycling of metallic lead or casing chips.

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Abbreviations

AAR	Applications Analysis Report
ABE	Alaskan Battery Enterprises (Superfund NPL Site)
ARAR	Applicable or Relevant and Appropriate Requirements
avg.	average
BESCORP	Brice Environmental Services Corporation
BSWS	BESCORP Soil Washing System
CEC	cation exchange capacity, meq/L
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
yd^3	cubic yards
EPA	U.S. Environmental Protection Agency
FWEI	Foster Wheeler Enviresponse, Inc.
gpm	gallons per minute
H_2SO_4	sulfuric acid
HSWA	Hazardous and Solid Waste Amendments to RCRA - 1984
kwh	kilowatt-hour
lb/ft^3	pounds per cubic foot
meq/L	milllequivalents per liter
mg/kg	milligrams per kilogram (ppm)
mg/L	milligrams per liter (ppm)
NPL	National Priorities List
OERR	Office of Emergency and Remedial Response
ORD	EPA Office of Research and Development
OSHA	Occupational Safety and Health Act
OSWER	EPA Office of Solid Waste and Emergency Response
POTW	publicly owned treatment works
ppb	parts per billion
ppm	parts per million
QAPP	Quality Assurance Project Plan

Abbreviations (Continued)

QA/QC	quality assurance/quality control
RCRA	Resource Conservation and Recovery Act of 1978
RFP	Request for Proposal
RI	Remedial Investigation
RREL	Risk Reduction Engineering Laboratory
SARA	Superfund Amendments and Reauthorization Act of 1986
sp gr	specific gravity, gr/cc
SITE	Superfund Innovative Technology Evaluation
TCLP	toxicity characteristic leaching procedure, mg/L
TER	Technology Evaluation Report
TM	trademark
TOC	total organic content
TPH	total petroleum hydrocarbons
tph	(short) tons per hour

Acknowledgements

This project was directed and coordinated by Hugh Masters, EPA SITE Project Manager in the Releases Control Branch of the Risk Reduction Engineering Laboratory, Edison, New Jersey.

This report was prepared for EPA's Superfund innovative Techndogy Evaluation (SITE) Program by Roger J. Gaire, P.E., of Foster Wheeler Enviresponse, Inc. (FWEI) under Contract No. 68-C9-0033. FWEI, supervised by Michael Merdinger, performed field activties. including sampling. Laucks Testing Laboratories. Inc. performed the chemical analyses for this SITE Demonstration. Dr. James Stumbar of FWEI conducted a technical review. The cooperation and participation of BESCORP throughout the course of the project and in the review of this report are gratefully acknowledged.

Keith Rose, Remed ial Project Manager of EPA Region 10, provided assistance and guidance in initiating the project and in lnterpretlng and responding to regulatory requirements.

Section 1
Executive Summary

1.1 BACKGROUND

In 1986, the U.S. Environmental Protection Agency (EPA) established the Superfund Innovative Technology Evaluation (SITE) Program to promote the development and use of innovative technologies to remediate Superfund sites. Technologies in the SITE Program are analyzed in two documents, the Technology Evaluation Report and the Applications Analysis Report. This Applications Analysis Report evaluates the applicability of the Brice Environmental Services Corporation (BESCORP) Soil Washing System (BSWS), and estimates the costs of operating it based on available data. Data not generated from the SITE Demonstration were provided by BESCORP, the technology developer.

The BSWS was evaluated under EPA's SITE Program, based on a Demonstration Plan agreed to by EPA and BESCORP. The Demonstration was conducted at the Alaskan Battery Enterprises (ABE) Site in Fairbanks, Alaska on the basis of a remedial investigation (RI) report and the site's inclusion on the National Priorities List (NPL). The primary objectives of the BSWS SITE Demonstration consisted of the following:

- Assess the ability of the process to comply with EPA's lead cleanup goals for redeposit of washed soil at the site (less than 1,000 mg/kg total lead and less than 5 mg/L TCLP lead),
- Determine if the BSWS can achieve greater than 75 percent process efficiency by cleaning sufficient percentages of contaminated graval and sand to the levels suitable for redeposit, and
- Develop economic data for the BSWS.

Secondary objectives were as follows:

- Determine if the washed battery casing chips meet the cleanup goals,
- Evaluate the BSWS reliability, and
- Document the operating conditions of the BSWS for application to other hazardous waste sites.

This report provides information based on the results from the SITE Demonstration and related case studies. This information is necessary if the BSWS techndogy is to be considered for use on Superfund and Resource Conservation and Recovery Act (RCRA) hazardous waste sites. Section 2 of this report presents an overview of the SITE Program, explains how the SITE Program results are documented, and lists key contacts. Section 3 discusses the SITE Demonstration objectives, describes the Demonstration, and relates its findings to the technology's application. This includes potentially applicable state and federal environmental regulations, the effects of waste characteristics and operating parameters on technology performance, applicable media, and personnel issues. Section 4 summarizes the costs of implementing the technology. The Appendices provide A) a description of the BSWS techndogy, B) BESCORP's claims regarding this techndogy. C) a summary of the SITE Demonstration results, and D) information from case studies prepared by BESCORP.

1.2 OVERVIEW OF THE SITE DEMONSTRATION

The BSWS was demonstrated at the ABE Site in August 1992. About 45 tons of soil contaminated with broken lead batteries were treated during the program. The soil was excavated, passed through a 2½" screen, and stockpiled as feed for the unit. The Demonstration included a series of shakedown tests and three test runs. As shown in Table 1, the feed soil analyses differed, to a minor degree, for each of the three runs. They necessitated certain proprietary process adjustments, but no major modifications.

Extensive data were cdlected to assess process performance. Liquid and solid samples were analyzed to determine lead partitioning and leaching potential of the process streams. Operating data were monitored and recorded, indudlng the raw waste feed rate, washed gravel and sand rates, electrical consumption, water makeup, pH, and temperature.

1.3 RESULTS AND CONCLUSIONS

In summary, the BESCORP Demonstration was a partial success in terms of removing large battery casings, casing chips, and discrete, metallic-lead particles from the washed gravel and sand fractions. The process effectively washed the graval fraction (Table 1) to meet the cleanup goals after process adjustments during the first run.

Although significant lead reduction was achieved in the sand fraction, the cleanup goals were not attained. However, Table 2 SITE laboratory analytical data for the minus ¼" to plus 10 mesh sand fractions, which were extracted from Table 5, indicate that this coarser portion

TABLE 1. BESCORP SITE DEMONSTRATION TEST RESULTS

	Feed soil					
	Total Pb mg/kg			Pb TCLP mg/L		
Run	Avg.	Range	Standard deviation*	Avg.	Range	Standard deviation
1	4,210	2,290 - 8,870	2,600	72	42-170	42
2	10,400	2,910 - 45,500	12,700	132	61-440	117
3	2,280	951 - 4,710	1,130	50	26-90	21
	Washed gravel					
1	2,540	32 - 9,630	3,200	1.0	0.4 - 1.6	0.4
2	903	17 - 6,640	2,070	0.8	0.5 - 1.1	0.2
3	15	5 - 32	8	0.2	0.1 - 0.6	0.2
	Washed sand -¼" to 150 mesh					
1	1,810	1,450 - 2,000	260	42	37 - 48	3
2	1,670	963 - 2,480	530	40	30 - 47	5
3	1,510	830 - 1,900	310	26	21 - 29	3

*The presence of metallic lead particles caused wide variations in the standard deviation. This is discussed in Appendix C.

TABLE 2. SITE LAB DATA FOR WASHED -¼" TO +10 MESH SAND
(Extracted from Table 5)

	Total Pb	Pb TCLP	Washed sand dry basis wt. %
	Avg.	Avg.	Avg.
SITE Run 1	191	4.8	44.3
SITE Run 2	162	5.7	43.7
SITE Run 3	69	1.7	38.3

TABLE 3. BESCORP LAB DATA FOR WASHED -¼" TO +80 MESH SAND*

	Total Pb mg/kg	Pb TCLP mg/L
	Avg.	Avg.
SITE Run 1	184	2.6
SITE Run 2	185	4.4
SITE Run 3	225	2.5

*The data above were not generated during the SITE Demonstration, but developed in vendor laboratory tests that did not employ U.S. EPA QA/QC procedures.

of the washed sand (about 40%) is substantially within the cleanup goals.

The data in Table 3 suggest process performance could be improved; however, no SITE data were developed to verify this conclusion. In Appendix B, BESCORP discusses post-Demonstration tests on the washed sand fraction. Based on these tests, BESCORP claims that the addition of an attrition scrubber, plus size separation (at plus 80 mesh) in a third separation chamber, would improve the performance of the BSWS.

The data provide a basis for the following conclusions:

- Lead removal (process) efficiencies in the three Demonstration test runs, measured as the percentage of lead removed from the gravel and sand fractions of the feed, were 26, 91, and 77, respectively. The higher removal efficiencies during Runs 2 and 3 are traceable to process adjustments made during the first run. Total lead removal, based on the lead content of all the feed fractions, reached 61, 93, and 85 percents,respectlvely. Calculations are presented in Section C.2.3.
- The process efficiency, which is represented by the washed gravel and sand (minus 2½" to plus 150 mesh) that meet EPA cleanup goals, expressed as a percentage of the feed that was greater than 150 mesh, improved significantly from 11 to 32 to 49 percent during the three runs. However, process efficiency did not approach the 75 percent SITE objective. The failure of the sand fraction to meet the cleanup goals contributed significantly to the loss in process efficiency.
- The three runs produced the following battery casing chip removal efficiencies (measured as the percentage of chips removed from the gravel and sand fraction): 97, 100. and 70, respectively. As expected, none of the Demonstration runs produced a washed casing chip fraction that met the EPA cleanup goals for redeposit.

- The cost to remediate **30,000 yd³** or 56,362 tons (dry) of contaminated soil, using a 20-tph modified commercial BSWS, Is estimated at $165/ton, assuming the system is on-line 80 percent of the time. This cost excludes solid-waste effluent-shipping costs to a RCRA landfill. The modified unit adds an attrition scrubber and a third separation chamber to yield a smaller washed gravel/sand fraction (mlnus 2½" to pius 80 mesh), which BESCORP claims will meet the cleanup goals as shown in Table 4.

  On thls basis, BESCORP projects a process efficiency of about 71 percent for the ABE-Site-type soil. In addltion, BESCORP projects both lead and casing chip removal efficiencies in the 20-tph unit to be greater than 90 percent, due to improved process control and elimination of bottlenecks in the Demonstration unit. No SITE Demonstration data are available to verify these projections.

- The BSWS is adaptable to soils containing battery casings, casing chips, or metallic lead. Much of the lead removal is achieved by separation of the battery casings and metallic lead from the feed soil.

- The unit operated at feed rates from 2.4 to 4.2 tph wfth a process on-line reliability of 87 percent. Scale-up risk to a 20-tph commercial unit is minimal, even with the addition of equipment for sand washing and a clarifier sludge vacuum filter for minimizing water loss.

- The effectiveness of the BSWS as a volume reduction unit is dependent on (1) the insolubility of the lead compounds In the washing medium, (2) the lead separation from the gravel and sand fractions by density separation that removes discrete, metallic-lead particles and by sieving that removes the contaminated fines, and (3) the feed soil particle size distribution.

  Treatability studies on representative feed soil are required to determine the cut point of washed gravel/sand fraction that meets the EPA cleanup goals and to predict the effectiveness of the BSWS on other feedstocks.

TABLE 4. VENDOR'S PROJECTED COMMERCIAL PERFORMANCE

Feed soil		Washed gravel		Washed sand -1/4" to +80 mesh	
Total Pb mg/kg	Pb TCLP mg/L	Total Pb mg/kg	Pb TCLP mg/L	Total Pb mg/kg	Pb TCLP mg/L
Avg.	Avg.	Avg.	Avg.	Avg.	Avg.
5,600	85	150*	0 5*	200*	3*

*The data above were not generated during the SITE Demonstration, but developed in vendor laboratory tests that did not employ U.S. EPA QA/QC procedures.

Section 2
Introduction

2.1 THE SITE PROGRAM

The EPA Office of Solid Waste and Emergency Response (OSWER) and the Office of Research and Development (ORD) established the Superfund lnnovatlve Technology Evaluation (SITE) Program in 1986 to promote the development and commercialization of innovative technologies to remediate Superfund sites across the country. Now in its eighth year, the SITE Program fs helping to provide the treatment technologies necessary to meet new federal and state cleanup standards aimed at permanent remedies. rather than short-term correctlons, The SITE Program indudes four major elements: the Demonstration Program, the Emerging Technologies Program, the Measurement and Monitoring Technologies Program, and Technology Information Services.

The major focus has been on the Demonstration Program, designed to provide engineering and cost data on selected technologies. EPA and the technology developers participating In the program share the cost of the demonstration. Developers are responsible for demonstrating their innovative systems, usually at Superfund sites agreed upon by EPA and the developer. EPA Is responsible for sampling and analysis activities and test result evaluation. The outcome is an assessment of the technology's performance, reliability, and cost. This information, used in conjunction with other data, enables EPA and state decision-makers to select the most appropriate technologies to remediate Superfund sites.

Innovative technology developers apply to the Demonstration Program by responding to the annual EPA solicitation. To qualify for the program, a technology devdoper must have a pilot- or full-scale unit and offer some advantage over existing technologies. Mobile technologies are of particular interest to the EPA.

Once EPA has accepted a proposal, the SITE Program, the developer, the EPA Reglonal offices, and state agencies work together to identify a site containing wastes suitable for testing the capabilities of the technology. The EPA SITE Program prepares a detailed sampling and analysis plan designed to thoroughly evaluate the technology and to ensure that the demonstration test data are reliable. A demonstration may require from a few days to several months, depending on the type of process and the quantity of waste needed to assess the technology.

In regard to the BSWS, where steady state can be achieved within an hour from startup, a minimum of three demonstration runs, each requiring 5 to 6 hours of steady state operation, were necessary to evaluate this process. Ultimately, the Demonstratlon Program leads to an analysis of the technology's overall applicability to Superfund sites.

The Emerging Technologies Program focuses on conceptually proven, but untried technologies. These technologies are in an early stage of development involving laboratory or pilot testing. Successful technologies are encouraged to advance to the Demonstration Program.

The Measurement and Monitoring Technologies Program identifies existing technologles that can improve field monitoring and site characterlzatlons. It supports the development and demonstration of new technologies that **provide faster,** more cost-effective real-time data on contamination and cleanup levels. Finally, lt formulates the protocols and standard operatlng procedures for demonstrated methods and equipment.

As part of the SITE Program's Technology Information Services, an Applications Analysis Report and Technology Evaluation Report are published at the conclusion of each demonstration. Research reports on emerging technology projects are also produced. Results and status updates are distributed to the user community-EPA Regions, state agencies, remediation contractors, and responsible parties-through many media and activities.

2.2 SITE *PROGRAM REPORTSTS*

The evaluation of technologies demonstrated in the SITE Program is presented in two documents: the Technology Evaluation Report (TER) and the Applications Analysis Report (AAR): The TER contains a comprehensive description and complete results of the demonstration sponsored by the SITE Program. It details the technology process, the waste used for the demonatration, sampling and analysis activities during the demonstration, the data generated, and the quality assurance program.

The scope of the AAR Is broader than the TER. It encompasses discussions of Superfund applicatlons and estimation of technology costs. The AAR compiles and summarizes the results of the SITE Demonstration, the vendors design and test data, and information gathered from other laboratory and field applications of the technology. In addition to discussing the technology's advantages, disadvantages, and limitations, it estimates the costs of the technology for different situations, based on data available from pilot- and full-scale applications. The AAR discusses factors that have a major impact on costs and performance, such as site and waste characteristics.

The amount of data available for the evaluation of an innovative technology varies widely. Data may be limited to laboratory tests on synthetic waste or may include performance data on actual wastes treated at the pilot- or fullscale level. Regarding Superfund applications, there are limits to conclusions that can be drawn from a single field demonstration. A successful field demonstration does not necessarily ensure that a technology will be widely applicable or fully developed to the commercial scale. The AAR attempts to integrate whatever Information is available and draw reasonable conclusions. The AAR is useful when considering the selection of a Suparfund cleanup technology: it represents a critical step in the technology's development and commercialization.

2.3 KEY CONTACTS

For more information on the development of BSWS for contaminated soil, please contact the following individuals:

EPA SITE Demonstration Project Manager

Mr. Hugh Masters
U.S. EPA - ORD
Releases Control Branch (MS-104)
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Edison, New Jersey 08837-3679
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Section 3
Technology Applications Analysis

3.1 INTRODUCTION

This analysis addresses the potential applicability of the BSWS to Superfund sites and other locations where contamination from lead batteries is of primary interest. The EPA tracks the development of control technologies [1,4,5] for remediation of lead battery recycling sites because these sltes represent a major source of hazardous material. BESCORP is currently developing applications of their process to treat radioactive wastes and organic contaminants. However, these activities are outside the scope of this AAR.

The SITE Demonstration at ABE provides a limited database for conclusions on the effectiveness and the applicability of the technology to other cleanups. To understand the potential applicability of the BSWS, the database needs to be expanded with information from recent particle-size separation tests, conducted subsequent to the SITE Demonstration. These data have resulted in system modifications incorporated into the commercial-scale plant in order to improve the BSWS performance.

The observations and conclusions, summarized below, are drawn from the SITE study and the above-mentioned supplemental information. Discussions cover site and soil characteristics, impact of state and federal environmental regulations, applicable media, and personnel factors. Additional information about the BESCORP process (a process description, vendor claims, a summary of the Demonstration test results, and case studies of treatability tests), is provided in the Appendices.

3.2 CONCLUSIONS

The BESCORP Demonstration was partially successful in removing large battery casings, battery casing chips, and discrete, metallic-lead particles from the washed gravel and sand fractions. The process effectively washed the gravel fraction to meet the cleanup goals (Table 5) after process adjustments during the first run. Although significant lead reduction was achieved in the sand fraction, the cleanup goals were not attained. However, SITE analytical data for the minus 1/4" plus 10 mesh sand fraction (Table 6) indicate that the coarser portion of the washed sand (about 40%) is substantially below the cleanup limits. These data suggest process performance could be improved; however, no SITE data were developed to verify this conclusion. In Appendix B, BESCORP discusses post-Demonstration tests on the washed sand fraction. Based on these tests, BESCORP claims that the addition of an attrition scrubber, plus size separation (at plus 80 mesh) in a third separation chamber, would improve the performance of the BSWS.

The specific conclusions are as follows:

- Lead removal (process) efficiencies in the three Demonstration test runs, measured as the percentage of lead removed from the gravel and sand fractions of the feed, were 28, 91, and 77, respectively. The higher removal efficiencies during Runs 2 and 3 are traceable to process adjustments made during the first run. Total lead removal measurements, based upon the lead content of all feed fractions, were 61, 93, and 85 percents, respectively. Calculations are presented in Section C.2.3.

- The process efficiency, which is represented by the washed gravel and sand (minus 21/2" to plus 150 mesh) that meets EPA cleanup goals, expressed as a percentage of the feed that was greater than 150 mesh, improved significantly from 11 to 32 to 49 percent during the threeruns. However, process efficiency did not approach the 75 percent

TABLE 5
SUMMARY OF KEY PROCESS STREAM CHARACTERIZATION DATA

Stream 1A** feed soil average SS1 analysis	Casing chips wt % dry	Total moist wt %	pH	Soil fraction: 2.5 to 1/4" mesh Pb mg/kg	2.5 to 1/4" mesh Wt % dry	1/4" to 10 mesh Pb mg/kg	1/4" to 10 mesh Wt % dry	10 to 150 mesh Pb mg/kg	10 to 150 mesh Wt % dry	< 150 mesh Pb mg/kg	< 150 mesh Wt % dry	Composite Pb mg/kg	Composite Std. dev.***	TCLP Pb mg/L	TCLP Std. dev.***	CEC meq/L	TOC Wt% dry	TPH mg/kg
Run 1*	6.0	7.3	6.6	1,080	57.2	3,650	7.8	5,670	23.9	17,700	11.0	4,210	2,600	72	42	2.7	2.0	240
Run 2*	5.0	7.1	6.7	11,600	48.1	8,900	9.5	6,840	31.3	16,000	11.3	10,400	12,700	132	117	2.7	1.5	228
Run 3*	1.7	5.3	7.1	497	45.1	824	9.7	3,340	35.7	8,210	9.5	2,280	1,130	50	21	7.1	1.2	117

Stream 2** gravel average SS2 analysis	Casing chips wt % dry	Total moist. wt%	pH	2.4 to 1/4" mesh wt% dry	1/4" to 150 mesh wt% dry	<150 mesh wt% dry	Composite Pb mg/kg	Composite Std. dev.***	TCLP Pb mg/L	TCLP Std. dev.***
Run 1*	0.4	1.7	7.2	98.3	1.7	0.02	2,540	3,230	1.0	0.4
Run 2*	0.0	1.3	7.0	96.9	1.1	0.04	903	2,070	0.8	0.2
Run 3*	1.2	3.9	6.7	96.3	1.6	0.04	15	8	0.2	0.2

Stream 3** sand average SS3 analysis	Casing chips wt % dry	Total moist. wt%	pH	Soil fraction: 1/4" to 10 mesh Pb mg/kg	1/4" to 10 mesh Pb, TCLP mg/L	1/4" to 10 mesh Wt% dry	<10 mesh Pb mg/kg	<10 mesh Wt% dry	<150 mesh Wt% dry	Composite Pb mg/kg	Composite Std. dev.***	TCLP Pb mg/L	TCLP Std. dev.***
Run 1*	0.0	11.7	6.3	191	4.8	44.3	3,110	55.7	0.5	1,810	256	42	3
Run 2*	0.0	11.4	6.4	162	5.7	43.7	2,820	56.3	1.0	1,670	526	40	5
Run 3*	0.0	12.7	6.6	69	1.7	38.3	2,400	61.7	1.3	1,510	306	26	3

* Run 1 – average of 7 data points
  Run 2 – average of 9 data points
  Run 3 – average of 8 data points

** See Figure 2 for stream identification.

*** The presence of metallic lead particles caused wide variations in the standard deviation. This is discussed in Appendix C.

TABLE 6. LEAD DISTRIBUTION

Run	-¼" to +10 mesh fraction					
	Feed soil - SS1*		Sand fraction - SS3*			
	Total Pb mg/kg	Standard deviation	Total Pb mg/kg	Standard deviation	Pb TCLP mg/L	Standard deviation
1	3,650	3,207	191	24	4.8	1.0
2	8,899	9,012	162	36	5.7	1.0
3	824	872	69	31	1.7	1.1
	-10 mesh to +150 mesh fraction					
1	5,671	1,446	3,114	549		
2	6,844	2,118	2,822	865		
3	3,338	1,900	2,400	485		

*See Figure 2 for sample location

SITE objective. The failure of the sand fraction to meet the cleanup goals contributed significantly to the loss in process efficiency.

- The three runs produced the following battery casing chip removal efficiencies (measured as the percentage of chips removed from the gravel and sand fraction): 97, 100, and 70, respectively. As expected, none of the Demonstration runs produced a washed casing chip fraction that met the EPA cleanup goals for redeposit.

- The BSWS is adaptable to soils containing battery casings, casing chips, or metallic lead. Much of the lead removal is achieved by separation of the battery casings and metallic lead from the feed soil.

- The unit operated at feed rates from 2.4 to 4.2 tph with a process on-line reliability of 87 percent. Scale-up risk to a 20-tph commercial unit is minimal, even with the addition of equipment for sand washing and a clarifier sludge vacuum filter for minimizing water loss.

- The effectiveness of the BSWS as a volume reduction unit depends on (1) the insolubility of the lead compounds in the washing medium, (2) the lead separation from the gravel and sand fractions by density separation that removes discrete, metallic-lead particles and by sieving that removes the contaminated fines, and (3) the feed soil particle size distribution. Treatability studies on representative feed soil are required to determine the cut point of washed gravel/sand that meets the EPA cleanup goals and to predict the effectiveness of the BSWS on other feedstocks.

3.3 *TECHNOLOGY EVALUATION*

3.3.1 Lead Battery Sites

A total of 44 CERCLA lead battery sites are located throughout the United States, including 22 on the Superfund National Priority List (NPL). The ABE Site is on the NPL. Batteries account for over 80 percent of the lead used in the United States; about 50 percent of It is recycled lead from battery-breaking operations. There are 29 forms of commercially recyclable lead [2] including five from batteries and two found in Superfund-type soils and cleanup materials/wastes. Battery casings and chips are also sources of potentially recyclable material, primarily as a fuel supplement in secondary (and possibly primary) lead smelters. However, no such commercial operations exist.

Lead is the primary contaminant found in soils, sediments, and sludges at these sites. Concentrations ranging up to seven percent have been encountered. (The highest at ABE was 4.5 percent.) Metallic lead (Pb), lead sulfate ($PbSO_4$), lead oxide (PbO), and lead dioxide (PbO_2) are the predominant lead species found at lead battery sites; these species were found at ABE by electron microscope analyses in the Remedial investigation (RI) *[3].*

Sites wkh carbonate soils generally contain lead carbonate **($PbCO_3$), hydrocerussite ($Pb_3(CO_3)_2(OH)_2$)**, or lead hillite **($Pb_4SO_4(CO_3)_2(OH)_2$).** The ABE soil is low in carbonates [3]. Other heavy metals such as antimony, arsenic, cadmium, and copper are sometimes present, but usually in relatively low concentrations. At ABE, these metals measured below action levels.

Soil cleanup goals vary, depending on site-specific factors such as exposure routes, location of humans, and sensitive environmental receptors. In spite of this site-to-site variability, two common cleanup goals recur. One of these requires reduction of lead concentrations in the soil, sediment, or sludge to the point that the leachate yields less than five mg/L of lead when subjected to an EPA-mandated leaching procedure (i.e., TCLP).

Soils with TCLP leachates above five mg/L lead are considered to be hazardous waste, which means that the soils generally cannot be placed in a landfill until treated to yield a leachate less than five mg/L lead. A second common cleanup goal is the reduction of the total lead content In residential soil to a level from 500 to 1000 mg/kg. At ABE, the EPA goals were treatment to less than 1,000 mg/kg total lead and less than five mg/L TCLP lead.

In terms of similarties with the ABE Site, such as cleanup goals, lead species, battery casings/chips, and the presence of other heavy metals, the BSWS Is potentially applicable to many of the 44 CERCLA lead battery sites.

3.3.2 Soil Washing Process

The BSWS, used in the SITE Demonstration, is a water-based volume reduction unit that uses trommel agitation, attrition scrubbing, high-pressure washing, and particle-size and density separation to remove lead, lead compounds, and battery casing chips from soil contaminated by broken lead batteries. The lead removal system, shown in Figure 1, uses a revolving trommel washer (containing a drum screen with high-pressure water sprays), a casing chip separator, two counter-flow separation chambers, and a density separator. The water recycling subsystem employs a dewatering spiral classifier, a clarifier, and a filter.

3.3.3 Feed Soil Characterization

The applicability of the BSWS as a volume-reduction soil washer for lead battery sites depends on the following feed soil characteristics:

- **The lead compounds** should be relatively insoluble in the washing fluid to minimize lead dissolution into the aqueous phase. Low soil pH will increase this dissolution. The ABE soil was fairly neutral (6.5 to 7.1 pH). Only water, with no additives such as acids, bases, or surfactants, was used as the washing medium; in all the test runs, the dlssolved lead concentration In the aqueous phase never exceeded 1 mg/L. For this process, higher lead concentrations in the aqueous phase could adversely affect the TCLP lead value of the washed gravel and sand.

- ***L e d separation from the gravel/sand fraction (solid phase particles)*** Is an essential feature of the BSWS and it is linked to certain feed soil characteristics in combination with treatability studies. The process has demonstrated efficient removal of discrete, metallic-lead particles from the gravel and sand fractions by density separation. Lead compounds such as **$PbSO_4$** adhere to the larger gravel/sand particles of the feed, either as very fine particle agglomerates or precipitated coatings, which must be liberated through scouring (via attrition and agitation) for efficient removal from the gravel and sand fractions (by size separation).

  Soil cation exchange capacity (CEC) and total organic carbon (TOC) content (Table 5) also Influence process efficiency. High CEC (over 8 meq/L) indicates large quantities of fine day particles that may retain lead [6]. High TOC (over 10 wt%) indicates large quantities of organic materials (e.g., humic acids) that also may retain lead. The ABE soil contained low average CEC and TOC values at 4.2 meq/L and 2 wt%, respectively. Treatability tests would verify whether the BSWS can economically achieve site-specific cleanup goals.

  Prior to the SITE Demonstration, treatability tests (Appendix D) on ABE soil samples (used for the RI analysis) indicated sufficient lead separation to

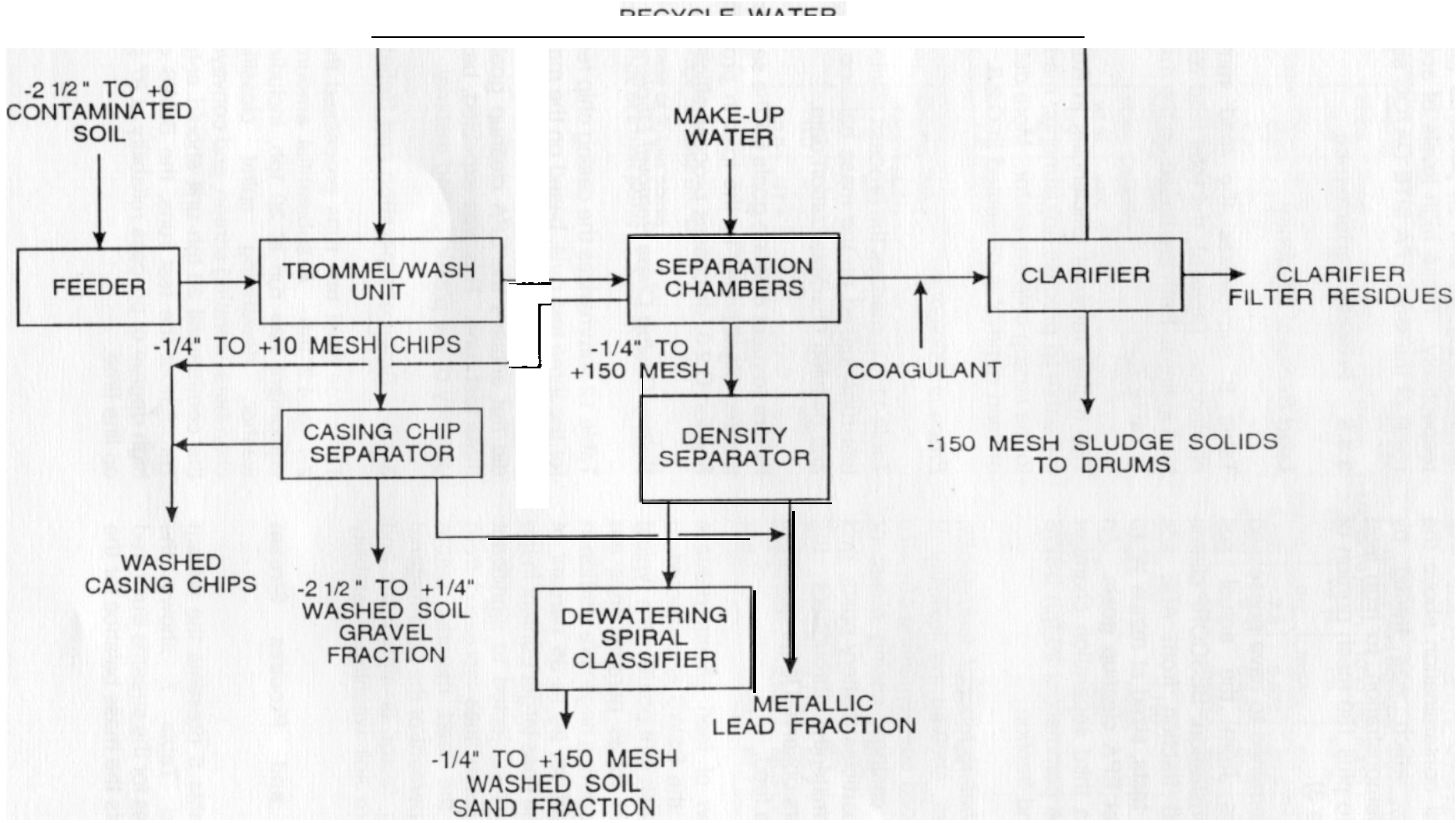

Figure 1. The BESCORP Soil Washing System.

effectively clean (to EPA goals) the soil down to 150 mesh. However, lead analyses of the washed sand fraction (minus ¼" to plus 150 mesh) from the three test runs indicated lead contamination above the EPA limits (Table 5), which was traced by BESCORP, after the Demonstration, to high lead levels in the minus 80 to plus 150 mesh portion of the washed sand (Table 3).

The RI sample was determined to have possessed different characteristics from the actual soil excavated for the Demonstration. BESCORP claims that the washed sand fraction from ABE soil excavated for the SITE tests, sized at minus ¼" to plus SO mesh, will meet EPA cleanup goals. An attrition scrubber and a third separation chamber have been added to the commercial 20-tph BSWS unit to produce this sand fraction.

- Adaptability ***to handle*** heterogeneous feedstocks, as demonstrated at ABE, showed the flexibility of the BSWS in handling feed soil containing any size or quantity of battery casings, casing chips, or discrete, metallic-lead particles (battery posts, grid plates, etc.). Intermittently throughout the Demonstration, operators observed large quantities of these materials in the feed.

- ***Particle size distribution*** of feed affects process performance. At ABE, the BSWS is projected to clean soil down to 80 mesh (cut point). In a typical soil washing system, 20 to 35 percent fines are normally acceptable, assuming negligible attrition in the process. This would set 20 to 35 percent of minus 80 mesh soil as the fines target content in the feed. The ABE soil was subjected to significant attrition; the minus 80 mesh fines increased from about 12 percent of the feed material before processing to about 30 percent of the feed material after processing. This factor is significant and should be part of future soil washing treatability studies.

3.3.4 Mass Balances and Process Stream Characterization

For the three SITE runs, Table 5 presents the stream characterization data and Table 7 shows the corresponding mass balances for the streams illustrated by Figure 2. Table 8 presents the mass balance for the commercial unit. Mass balances for the three runs, expressed as the percentage of total out based on total in, were 107, 99, and 98 percents (dry sdids basis), respectively. These high levels of accuracy were the result of the strict EPA SITE QA/QC standards.

3.3.5 Process Performance

Lead Removal Efficiency

Table 9 summarizes the lead removal (process) efficiencies; Table 10, the total lead removal, including lead in fines. Both are based on the mass balance data in Table 7.

The higher removal efficiencies In Runs 2 and 3 are traceable to process adjustments, made during Run 1, to the casing chip separator. More detailed discussion on lead removal is presented in C.2.3.

Process ***Efficiency***

Table 11 summarizes the process efficiency for the three test runs, based on the mass balance data in Table 7 and detailed characterization data.

Failure to meet cleanup goals for the sand fraction contributed significantly to the loss in process efficiency. Section C.2.3. discusses process efficiency in detail.

Battery Casing Chips Removal Efficiency

Table 12 summarizes the casing chip removal efficiency for the three test runs, based on the mass balance data In Table 7. The washed casing chip fraction (Stream 7) did not achieve the EPA cleanup goals in any of the three test runs. This was expected, based on the high porosity of the plastic casing material.

3.3.6 Scale of Operation and Reliability

The three SITE test runs processed throughputs from 2.4 to 4.2 tph. A substantial amount of the BSWS equipment has run at 20 tph, including the trommel washer, dewatering spiral classifier, separation chambers. vibrating screen, and conveyors. Scale-up to the commercial 20-tph unit should entail minimal risk. Throughout the test runs, the BSWS demonstrated a high degree of process reliability at 87 percent average on-line time.

TABLE 7
MASS BALANCES FOR THE THREE SITE DEMONSTRATION RUNS

Stream	Description	Wet total lbs/hr	Dry total lbs/hr	Lead -21/2" to +150 mesh lbs/hr	Lead Composite lbs/hr **	Casing chips -21/2" to +150 mesh lbs/hr	Casing chips Composite lbs/hr **
	Run 1						
	Streams in						
1A	Feed soil	4,660	4,320	9.7	18.2	259	259
5	Make-up water	1.580					
	Total in	6.240	4.320		18.2	–	259
	Streams out						
2	Gravel	2,140	2,100		5.3	6.4	6.4
3	Sand	1,080	954		1.7	0.0	0.0
4	Clarifier sludge’	3,340	1,150		12.1	N/A	
7	Washed casing chips	382	357		39.0	N/A	–
8	Heavy metal (lead) fraction	46	44		1.7	N/A	–
9	Clarifier filter residue	12	6		0.02	N/A	–
	Total out	7,000	4.611		59.8		–
	Total out x 100 = % balance / Total in	112%	107%	–	329%	–	–
	Run 2						
	Streams in						
1A	Feed soil	4,950	4,590	39	47.7	230	230
5	Make-up water	2,540	–	–	–	–	–
	Total in	7,490	4,590	–	47.7	–	230
	Streams out						
2	Gravel	1,810	1,790	–	1.6	0.0	0.0
3	Sand	1,210	1,070	–	1.8	0.0	0.0
4	Clarifier sludge*	3,930	1,290	–	10.9	N/A	–
7	Washed casing chips	333	321	–	32.8	N/A	–
8	Heavy metal (lead) fraction	60	55	–	2.1	N/A	–
9	Clarifier filter residue	25	8	–	0.02	N/A	–
	Total out	7,368	4,534	–	49.2	–	–
	Total out x 100 = % balance / Total in	98%	99%	–	103%	–	–
	Run 3						
	Streams in						
1A	Feed soil	8,260	7,830	11.7	17.8	133	133
5	Make-up water	3,410	–				
	Total in	11,670	7,830		17.6		133
	Streams out						
2	Gravel	3,540	3,440	–	0.1	41.3	41.3
3	Sand	1,960	1,710	–	2.6	0.0	0.0
4	Clarifier sludge*	5,510	1,950	–	11.5	N/A	–
7	Washed casing chips	375	364	–	0.5	N/A	
8	Heavy metal (lead) fraction	162	145	–	5.7	N/A	
9	Clarifier filter residue	64	24	–	0.02	N/A	
	Total out	11,611	7,633	–	20.4		
	Total out x 100 = % balance / Total in	99%	97%	–	115%	–	–

* Unsettled clarifier sludge. This sludge settled/dewatered to about 40 wt% moisture in 48 hours.
** Composite of all feed fractions.
N/A – not analyzed

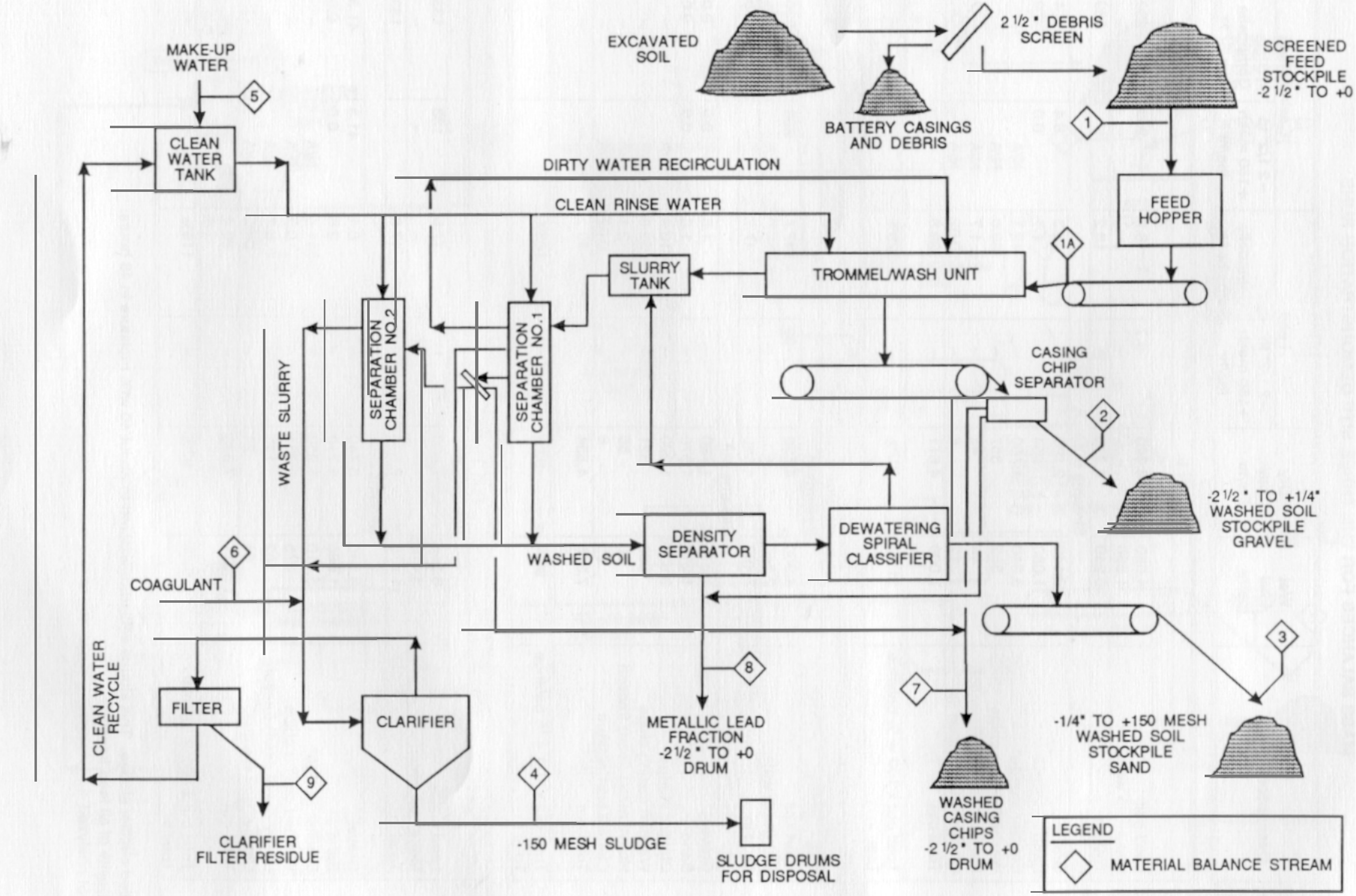

Figure 2. Simplified BSWS flow diagram for SITE demonstration.

TABLE 8
MASS BALANCE FOR COMMERCIAL UNIT

	Feed soil		Make-up Water	Washed gravel/ sand		Clarifier dewatered sludge cake/residue		Casing chips		Metallic lead fraction		Treated waste
	Dry total lb/hr	Water lb/hr	lb/hr	Dry total lb/hr	Water lb/hr	Dry total lb/hr	Water lb/hr	Dry total lb/hr	Water lb/hr	Dry total lb/hr	Water lb/hr	Water lb/hr
Average system balance	40,000	3,020	2,960	25,400	1,470	11,400	2,850	2,670	131	545	50	1,480
Solids (tph-dry)	(20)			(12.7)		(5.7)		(1.3)		(0.3)		
Water-gpm			6									3

TABLE 9. LEAD REMOVAL (PROCESS) EFFICIENCIES

Run	Lead, lb/hr: -21/2" to + 150 mesh feed fraction	Lead, lb/hr: -21/2" to + 150 mesh washed gravel and sand	Process removal efficiency %
1	9.7	7.0	26
2	39.0	3.4	91
3	11.7	2.7	77

TABLE 10. LEAD REMOVAL (TOTAL) EFFICIENCIES

Run	-21/2" total feed	-21/2" to +150 mesh washed gravel and sand	Total removal efficiency*
1	18.2	7.0	61
2	47.7	3.4	93
3	17.6	2.7	85

*For composite feed, all fractions

TABLE 11. PROCESS EFFICIENCY

Run	Washed gravel fraction: % Meeting cleanup goals	Washed gravel fraction: lbs/hr dry	Feed soil: -21/2" + 150 mesh lbs/hr (dry)	Process efficiency (%)
1	20	2,100	3,870	11
2	71	1,790	4,040	32
3	100	3,440	7,070	49

TABLE 12. CASING CHIP REMOVAL

Run	Casing chips, lb/hr		Removal efficiency %
	-21/2" to + 150 mesh Feed traction	-2½" to + 150 mesh Washed gravel end sand	
1	259	8.4	97
2	230	0	100
3	133	41 3	70

3.4 RANGES OF SITE CHARACTERISTICS SUITABLE FOR THE TECHNOLOGY

3.4.1 Site Selection

The BSWS commercial-scale unit is trailer-mounted: it can be moved from site to site. The following discussion of suitable site characteristics applies to this commercial-scale unit. Although the geological features of a site determine what equipment may be used within the contaminated area, the BSWS is usually assembled within the confines of the contaminated area or positioned so that the contaminated soil can be easily transported to the unit. Ultimately, the characteristics of the site must allow assembly of the system.

3.4.2 Topographical Characteristics

A level, graded area capable of supporting the trailer-mounted equipment is needed. The site must be clear to allow access to the facility. The topographical characteristics of the site should be suitable for the assembly of the unit and the feed system, including stockpiles.

3.4.3 Site Area Requirements

A minimum area of 1,000 square feet is required for the BSWS. Additionally. separate areas should be provided for storage of wastes generated during treatment and for feed preparation activities. Since the unit can be configured into many positions, the shape of the site is inconsequential, except where it limits access to the equipment.

3.4.4 Climate and Geological Characteristics

This treatment technology is limited to operating at temperatures above freezing. Generally, any site that is sufficiently stable to handle the weight of the trailers is suitable for this technology.

3.4.5 Utility Requirements

The BSWS requires access to electrical power and water. A 3-phase electrical source capable of providing 440 volts at 200 amps is required to install and to operate the unit. A minimum water flow rate of 10 gallons per minute (gpm) is also required. Finally, based on the BSWS Demonstration, wastewater disposal to a POTW, at the rate of about 10 gpm, is required. BESCORP claims that a commercial unit will not require a wastewater discharge. (See Appendix B.)

3.4.6 Size of Operation

The contaminated soil feed rate for the SITE Demonstration was approximately 2.4 to 4.2 tph. The projected soil feed rate for the commercial-scale unit is 20 tph. The layout of the commercial-scale system may be adjusted somewhat to conform to an optimum facility design plan. The area needed for on-site assembly of the system will vary with the configuration, requiring at least 1,000 square feet. The area for the feed stockpile should be sufficient to store 700 yd3 of soil.

3.5 APPLICABLE MEDIA

The BSWS can treat soils contaminated with lead from broken lead batteries found at lead battery recycling sites. The Demonstration test indicated that the unit is capable of separating battery casings, casing chips, and lead/lead compounds from gravelly/sandy soil fractions BESCORP projects that a commercial unit, treating ABE-type soil, could process material from 2½" to about 80 mesh (cut point) and meet the EPA cleanup goals proposed for ABE. Treatability tests on representative soil samples can determine site-specific performance and the corresponding cut point to meet the cleanup goals at other sites.

The process Is not effective in treating sludges or sediments because they contain a high percentage of fines. BESCORP claims to have applied their process, either in bench-scale or pilot-scale operation, to other contaminated feeds including radioactive wastes (Appendices B and D).

3.6 *ENVIRONMENTAL* REGULATION *REQUIREMENTS*

Under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) and the Superfund Amendments and Reauthorization Act of 1986 (SARA), EPA is responsible for determining the methods and criteria for removal of waste and resldual contamination from a site. The utility and cost effectiveness of the BSWS depends on the extent of decontamination necessary for site restoration and on the treatment appropriate to achieve the required cleanup levels for the particular site. If a waste exhibits a characteristic hazard (e.g., lead toxicity) treatment will be required. For the ABE site, EPA goals for redeposit of soil were established (i.e., total lead less than 1,000 mg/kg and TCLP lead less than 5 mg/L).

Since the use of remedial actlon that "... permanently and significantly reduces the volume, toxicity or mobility of hazardous subatances" Is strongly recommended (Section 121 of SARA), the BSWS would appear to be an attractive candidate for remediation of sites contaminated by lead batteries.

SARA also added a criterion for assessing cleanups that includes consideration of potential contamination of the ambient air. This supplements the general criteria requiring that remedies be protective of human health and the environment. Other than normal concerns about volumes of contaminated soils handled by workers and the dust generated during those operations, there appears to be mlnimal risk of contaminant exposure for workers or neighbors. Since the soil washing is a wet process, air emissions are minimal. BSWS-treated wastewater effluent (containing less than 1 mg/L Pb) during the SITE Project was suitable for discharge to the Fairbanks POTW.

While the SITE Project is exempt from formal permit requirements under the Resource Consewatlon and Recovery Act of 1976 (RCRA), the Hazardous and Solid Waste Amendments (HSWA) of 1984 and equivalent state regulations may require a RCRA permit for the entire commercial or large-scale system to operate as a hazardous waste treatment faclllty. In addition, a state-issued air permit and a water permit may be required to cover discharges from the system. Local requirements for these permits vary from state to state. Therefore, it Is important to review specific state regulations early in the planning stage.

3.7 PERSONNEL ISSUES

3.7.1 Training

Since personnel Involved with sampling or other activities close to the unit are required to wear Level D protection, 40-hour OSHA training that covers Personal Protective Equipment Applications, Safety and Health, Emergency Response Procedures, and Quality Assurance/Quality Control Is required. Additlonal training to address site activities, procedures, monitoring, and equipment associated with the technology is recommended. Personnel should also be briefed when new operations are planned, work practices change, or site conditions change.

3.7.2 Health and Safety

Personnel should be instructed on the potential hazards associated with the operation of the BSWS, recommended safety work practices, and standard emergency plans and procedures. Health and safety training should cover the potential hazards of exposure, monitoring, provisions for response to exposure, and the use and care of personal protective equipment. When appropriate, workers should have routine medical exams to monitor for exposure to lead. Health and safety monitoring and incident reports must be routinely filed; records of occupational illnesses and Injuries (OSHA Forms 101 and 200) must be maintained. Audits ensuring compliance with the health and safety plan should be performed.

Proper personal protective equipment should be available for proper use by on-site personnel. Different levels of personal protection will be required, based on the potential hazards associated with the site and the work activities.

Site monitoring should be conducted to identify the extent of hazards and to document exposures at the site. The monitoring results should be maintained and posted.

3.8 REFERENCES

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2. *Lead Recycling: 1992 Directory,* The Lead Industries Association, Inc. New York, NY. [Lead Media Hotline 1-800-922-LEAD]

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5. Gaire, R., A. Selvakumar, and T. Basu. Selection *of Control Technologies for Remediation of Lead Battery Recycling Sites.* Foster Wheeler Enviresponse. Inc. for EPA/RREL, Cincinnati, OH. EPA/540/2-91/014. July 1991.

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Section 4
Economic Analysis

4.1 INTRODUCTION

The primary purpose of this economic analysis Is to estimate costs (excluding profit) for BSWS commercial-scale remediation. With realistic knowledge of test costs, it should be possible to estimate the economics of operating similar-sized systems at other sites. The feed rate of the BSWS for the SITE Demonstration was 2.4 to 4.2 tph. The commercial unit is projected to operate at 20 tph.

This economic analysis is based on assumptions and cost figures provided by BESCORP, results of the SITE Demonstration, and best engineering judgement. The conclusions are presented In such a manner that the reader can vary the assumptions, as needed, and thus draw other conclusions.

This analysis assumes that the commercial-scale system is essentially the same soil washing equlpment evaluated in the Demonstration, with certain additions detailed In Appendix B. It also assumes that the performance of the modified commercial-scale equipment will improve over the SITE Demonstration performance (Appendix C), so that the gravel and sand fractions meet the cleanup goals that allow their redeposit on site.

Order-of-magnitude cost estimates provided in this section are generally +50 to -30 percent; they are representative of charges typically billed to the client by the vendor, exclusive of profit.

4.2 CONCLUSIONS

The commercial-scale BSWS appears to be applicable to remediation of soils contaminated with lead from lead batteries. The treatment cost to remediate 30,000 yd3 or 56,362 tons (dry) of contaminated soil, using a 20-tph modified commercial BSWS unit, is estimated at a total of $9.3 million, or $165/ton, when the system is on-line 80 percent of the time. This amount includes the solid-waste effluent cost for RCRA landfill disposal but excludes the expenses for manifesting and shipping to the RCRA landfill. It also does not cover total cleanup cost because 4 out of the 12 categories for complete cleanup were not included.

The modified BSWS unit adds an attrition scrubber and third separation chamber to yield a smaller washed gravel/sand fraction (minus **2½"** to plus 80 mesh) that BESCORP claims (See Appendix B.) will meet the cleanup goals. [The washed sand fraction, minus **¼" to** + 150 mesh in the SITE test runs, did not meet cleanup goals.] On this basis, BESCORP projects a process efficiency of about 71 percent for the ABE-type soil. In addition, BESCORP projects both lead and casing chip removal efficiencies, In the 20-tph unit, to be greater than 90 percent, due to improved process control and elimination of bottlenecks in the unit. Recycling markets for casing chips and the metallic-lead fraction would further reduce treatment costs. However, at this time, recycling markets for BESCORP casing chips and metallic lead have not materialized. Therefore, these materials have been included in the solid-waste effluent cost.

4.3 ISSUES AND ASSUMPTIONS

This section summarizes the major issues and assumptions used to develop the costs of the BSWS [I]. In general, assumptions are based on information provided by BESCORP. Certain assumptions account for variable site and waste parameters; they will need to be refined to reflect site-specific conditions. For purposes of this economic analysis, a hypothetical commercial-scale cleanup of the ABE site was assumed. The volume of contaminated soil to be treated is approximatdy 30,000 yd^3 with 6.6 wt% moisture and a bulk density of 149 lb/ft^3. The soil weight on a dry basis is then 56,362 short tons. About 46 tons were treated in the SITE Demonstration program.

4.3.1 Costs Excluded from Estimate

The cost estimates represent the charges typically billed to the client by the vendor but do not include profit. Many other actual or potential costs were not included in this estimate because site-speclflc engineering designs, beyond the scope of this SITE project, are required to determine those added costs. Certain costs that are considered to be the responsible party's (or site owner's) obligation, such as preliminary site preparation, permits, regulatory requirements, initiation of monitoring programs, waste disposal, sampling and analyses, and posttreatment site cleanup and restoration, are not included. These expenses tend to be site-specific. Calculations must be performed for each specific case. Wherever possible, applicable information is provided on these topics to facilitate site-specific calculations.

4.3.2 Utilities

To support the operation of the BSWS, a site must have clean water available at a flow rate of at least 40 gpm. Electric power at 440 volts is also required for the operation. A POTW trunk line is assumed to be located at the site boundary for discharge of treated wastewater.

4.3.3 Operating and Maintenance Schedules

Operating and maintenance schedules are based on the BSWS operations, conducted at 20 tph, 24 hours per day, 7 days per week. Excavation is scheduled at 84 tph, 8 hours par day, 5 days per week; assembly, 12 hours per day, 7 days per week. Excavation activities for feed preparation are concurrent with assembly, shakedown, and treatment operations. Time requirements for assembly, shakedown, startup, testing, and disassembly/decontamination are forecast at 1 week, 3 weeks, and 1 week, respectively, or about 35 days.

To treat 30,000 **yd^3** of feed soil at 20 tons/hr (dry) will take about 118 days. To account for both scheduled maintenance and unscheduled shutdowns, a 20 percent downtime is included, for an actual treatment time forecast of 148 days. Scheduled maintenance would be performed by a mechanic during the day shift. Total time on-site is estimated to be 183 days.

4.3.4 Labor Requirements

Labor **requirements for** excavation, equipment assembly, startup, treatment operations, decontamination, and demobilization are detailed in Section 4.4.5.

4.3.5 Capital Equipment and Fixed Costs

Annualized equipment and associated costs are pro-rated for the period that the equipment is on-site.

4.3.6 System Design and Performance Factors

Figure 3 shows a process flow diagram of a 20-tph mobile BESCORP commercial plant. This plant requires about 6 gpm (18 gal/ton dry soil) of make-up water and discharges about 3 gpm (9 gal/ton dry soil) of treated wastewater to a POTW where the expected lead content, based on the SITE Demonstration, is less than 1 mg/L Pb. The washed gravel/sand fraction is assumed to be clean enough for redeposit on-site. The metallic-lead fraction, plus the casing chips and battery casings, may be candidates for recycling to a secondary lead smelter. However, this issue was not part of the SITE Program, nor has it been investigated to date. Site-specific studies are required to determine the feasibility of recycling these materials. This study assumes that these materials will be disposed at a RCRA landfill. The clarifier- dewatered sludge cake will be contaminated and, therefore, will also require disposal at a RCRA landfill.

4.3.7 System Operating Requirements

Table C-3 (Appendix C) summarizes the mass balances for the three BSWS SITE Demonstration runs. An average system mass balance (Table 13) for the 20-tph BSWS commercial plant is developed from projected feed/product streams from Table C-3 with adjustments made for system modifications. Table 14 summarizes operating utilities and consumabies.

4.4 BASIS *OF ECONOMIC ANALYSIS*

For economic analysis EPA breaks down the overall cost into 12 categories:

- Site preparation
- Permitting and regulatory
- Equipment (amortized over 10 years)
- Startup
- Labor
- Supplies and consumables
- Utilities
- Effluent treatment and disposal
- Residuals/waste shipping, handling, disposal
- Analytical activities
- Facility modification, repair, and replacement
- Demobilization and decontamination

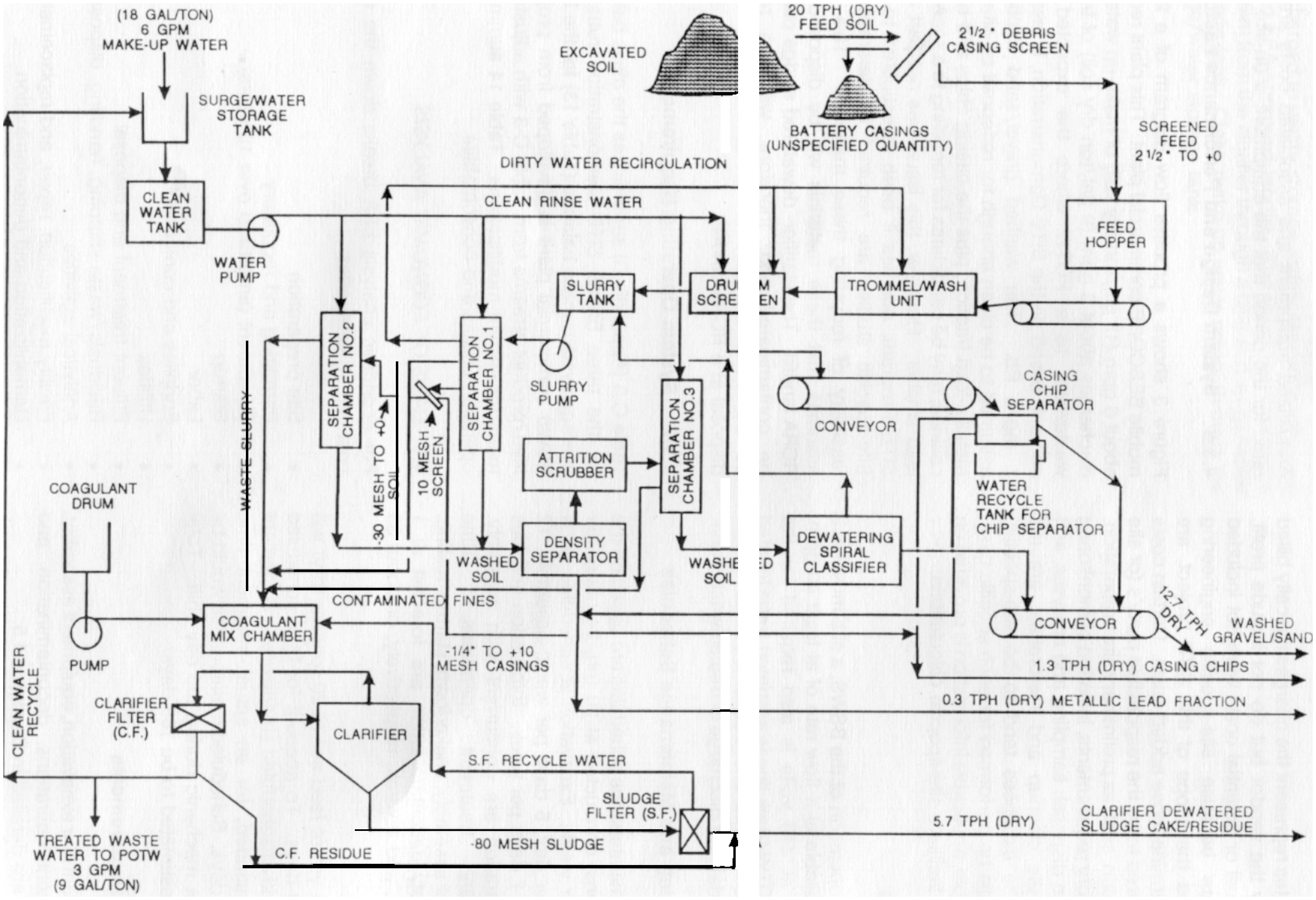


Figure 3. BSWS modified commercial-scale flow diagram.

TABLE 13. BSWS AVERAGE SYSTEM MASS BALANCE FOR COMMERCIAL UNIT

	Feed soil		Make-up water	Washed gravel/ sand		Clarifier dewatered sludge cake/residue		Casing chips		Metallic lead fraction		Treated waste
	Dry total lb/hr	Water lb/hr	lb/hr	Dry total lb/hr	Water lb/hr	Dry total lb/hr	Water lb/hr	Dry total lb/hr	Water lb/hr	Dry total lb/hr	Water lb/hr	Water lb/hr
Average system balance	40,000	3,019	2,956	25,364	1,470	11,383	2,846	2,668	131	545	50	1,478
Solids (tph-dry)	(20)			(12.7)		(5.7)		(1.3)		(0.3)		
[illegible]			[illegible]									3

TABLE 14. UTILITIES AND CONSUMABLES

Process operating utilities and consumables	Unit
Make-up water	18 gal/ton dry feed
Treated wastewater	9 gal/ton*
Electric power (440V)	4 kwh/ton
Coagulant	0.026 gal/ton
Diesel fuel	$0.25/ton

*This estimate is based on the BSWS Demonstration. BESCORP claims that a commercial unit will not require a wastewater discharge.

Some of these categories do not affect the costs of operating the BSWS. The 12 cost factors examined, as they apply to the BSWS. along with the assumptions used, are summarized in Table 15.

4.4.1 Site Preparation Costs

The analysis assumes that preliminary site preparation has been performed by the responsible party (or site owner). The amount of preliminary site preparation depends on the site. Site preparation includes site design and layout, surveys and site logistics, legal searches, obtaining access rights and/or adding roads, preparing support and decontamination facilities, installing utility connections, and erecting auxiliary buildings. These costs are site-specific; they are not included in the site preparation costs.

Site preparation activities. such as excavating hazardous-waste feed from the contaminated site, will be required at all sites. Therefore, they are included in this estimate. Estimates for site preparation are based on rental costs for heavy equipment, labor charges, and equipment fuel costs. Assuming a rate of 84 tph, excavation activities should be conducted for 8 hours per day, 5 days per week, over a period of 17 weeks. Rental equipment required to achieve the 84 tph rate includes an excavator at $1,260/week and a dump truck at $700/week. This equipment consumes approximately 5 gal/hr of diesel fuel.

4.4.2 Permitting and Regulatory Costs

Permitting and regulatory costs are generally the obligation of the responsible party (or site owner). These costs may include expenses for applications, actual permit, system monitoring requirements, and/or the development of monitoring and analytical protocds. Permitting and regulatory costs can vary greatly because they are site- and waste-specific. No permitting or regulatory costs are included in this analysis. Depending on the treatment site, however, such costs may be both expensive and time-consuming factors.

4.4.3 Equipment Costs

Soil Washing

Soil washing is not an "off-the-shelf " process; lt must be modified for site-specific conditions on a case-by-case basis. Factors such as contaminant type and level. cleanup criteria, soil mineralogy, and soil particle-size distribution must be considered when deslgnlng a treatment system. The soil Is first characterized to determine the nature and location of the contaminants. A strategy is then developed to effect the separations necessary to achieve the volume reduction required to meet regulatory goals. This is accomplished by concentrating the contaminants in a small volume of material while producing a washed soil product that meets appropriate cleanup criteria. The number, size. and type of unit operations required to accomplish the necessary separations will have en impact on the capital costs.

BESCOAP estimates the construction cost of a commercial, 20-tph mobile soil washing system to be $770,000. This was independently verified, using outside sources, purchasing experience, and good engineering judgement. Table 18 summarizes this estimate. The equipment list and quantities were compiled from Figure 3.

4.4.4 Startup Costs

Startup costs Include assembly of the BESCORP unit, shakedown, operator training, startup, performance tests, and initiation of health and safety monitoring.

Assembly

The BESCORP unit will be delivered to the site on two mobile trailers. Site-specific cost of transportation to the site Is excluded. Estimates assume that a level and bermed locatlon has been prepared at the site for the two BESCORP trailers.

Three mechanics, a boom truck operator, and a front-end loader operator will be required for 1 week (7 days, 12 hours per day in two 6-hour shifts) to assemble the unit and connect utilities-water, wastewater (POTW) lines, and power (440 volts). A boom truck at $5,000 per week and a front-end loader at $3,000/week will be rented. Dlesel fuel consumption is estimated at 4 gal/hr. The labor is itemized in Section 4.4.5.

Shakedown, Operator Training, Startup, and Performance Tests

BESCORP’s experience from the SITE Program showed that 3 weeks will be sufficient time to shake down the unit, start it up, train operations personnel, and perform several capacity tests to ensure that the unit meets performance criteria. Labor encompasses one project

TABLE 15. TREATMENT COSTS FOR THE BSWS MODIFIED COMMERCIAL UNIT*

Cost component	Cost	Cost distribution %
1. Site preparation (feed excavation only)	33,300($)	0.36
2. Permitting & regulatory	---	---
3. Equipment (amortized over 10 years)	31,200	0.34
4. Startup	32,000	0.34
5. Labor	1,131,000	12.14
6. Consumables and supplies		
Health & safety gear	50,000	0.54
Flocculant/coagulant	74,100	0.80
Fuel and lubricants	19,400	0.21
7. Utilities		
Process make-up water	1,000	0.01
Electric power	18,200	0.20
8. Effluent treatment & disposal		
Treated wastewater	1,700	0.02
Solid wastes	7,900,000	84.89
9. Residuals/Waste shipping, handling, and disposal	---	---
10. Analytical	---	----
11. Facility modification, repair/ maintenance, and replacement	5.700	0.06
12. Decontamination and demobilization	8.000	0.09
TOTAL	9,305,600	100.00

*Based On treatment of 30,000 yd^3 of contaminated soil by the 20-tph unit, operating with an 80% on-line factor

manager (day shift) who also performs health and safety functions, one lead operator, one equipment operator (payloader), three operators per 8-hour shift, and one mechanic for one 8-hour shift per day.

These personnel are Included in the total labor cost component (Section 4.4.5), which also covers living expenses for managers and supervisors. Maintenance staff, the boom/pay-loader operator, and operations personnel are locally hired. Personnel must be OSHA-trained in hazardous-waste operations.

Health and Sefety

The cost of health and safety equipment Is assumed to be similar to that used at ABE during the SITE Demonstration, where the only pollution Issues concerned noise and lead-contaminatad soil.

TABLE 16. BSWS CAPITAL EQUIPMENT COST BREAKDOWN

Equipment	Quantity	1993 cost, $*
Feed hopper/conveyor	1	20,000
Trommel washer unit	1	50,000
Attrition scrubber	1	30,000
Separation chambers	3	30,000
Clarifier	1	24,000
Sludge filter	1	90,000
Pumps	4	12,000
Casing chip separator	1	27,000
Conveyor	5	30,000
Density separator	1	6,000
Dewatering spiral classifier (sand screw)	1	16,000
Clarifier filter	1	10,000
2½" vibrating screen	1	92,000
Miscellaneous equipment		19,000
Total equipment cost		456,000
Installation labor/material**		220,000
Total installed		676,000
Contingency		94,000
Installed grand total equipment cost		770,000

*costs developed from January 1993 vendor quotes
**use 50% installation factor reference [2]

The project manager doubles as the health and safety officer on day shifts and a lead operator doubles at night. Personnel on-site must wear Level D protection as noted below. The cost is presented in Section 4.4.6. Depending on the site, however, local authorities may impose more stringent health and safety regulations, which may have significant impact on the project cost.

Health and Safety Equipment

Tyvek suits	Safety glasses
Double gloves	Decibel meter
Safety boots	Air RAM montor
Hard hats	Eyewash station
Ear plugs	Decontamination supplies

4.4.5 Labor Costs

Labor costs are divided into salaries and living expenses. Salaries include benefits and administrative/overhead costs but exclude profit. Living expenses ($130 per day per person) for all on-site personnel (project manager, lead operators, and supervisors) include sharing a rental car. Other employees are locally hired.

Excavation Labor Requirements andRates

From Section 4.4.1. the labor requirements are shown in Table 17.

BSWS Equipment Assembly Labor and Rates

From Section 4.4.4. the labor requirements are summariied in Table 18.

BSWS Operations Labor and Rates (Shakedown and Production)

Referring to Section 4.4.4. operations staff will consist of 1 lead operator, 3 operators, and 1 equipment operator (payloader). The BSWS will operate 24 hours per day (three 8-hr shifts per day), 7 days per week. Four crews will be assigned to a standard shift rotation, with each person working 40 hours per week and 8 scheduled overtime hours during each 4-week rotation. A project manager (who also performs health and safety functions) and a maintenance mechanic are scheduled for 5 days per week on the day shift. The BESCORP operations labor requirements and rates are detailed In Table 19. These requirements are the same for both shakedown and full production operations. Note that each operator works an average of 42 hours per week (one overtime shin every 4 weeks).

4.4.6 Supplies and Consumables

- Health and safety equipment (Level D). a consumable item, costs about $40,000 for the 183-day project.
- Fuel and lubricants should total about $19,400
- Coagulant consumption is about 0.026 gal/ton (dry feed).

4.4.7 Utilities

- Make-up water costs about $0.02/ton of dry feed based on 18 gal/ton at $1.00/ 1,000 gal.
- Electric power costs $0.32/ton based on 4 kwh/ton at $0.08 kwh.

4.4.8 Effluent Treatment and Disposal Costs

The treated wastewater, containing less than 1 mg/L total lead, should be suitable for discharge to a POTW. The responsible party or site owner must obtain a discharge permit from the local municipality. Typical cost (Fairbanks) is $3.35/ 1,000 gal. Cost per ton (dry feed) is then $0.03 at 9 gal/ton consumption-assuming a POTW trunk line is available at the site.

Contaminated solid effluent wastes including casing chips, metallic-lead fractions, and clarifier residue/dewatered sludge cake will be sent for disposal to a RCRA-permitted facility. In Table 13, these wastes total about 0.44 wet tons/ton of dry feed. This estimate includes the landfill cost of $138.60/ton of dry feed, based on a tipping fee at a RCRA landfill of $315/ton of lead-contaminated waste.

However, shipping, handling. manifesting, and waste profile analyses are assumed to be the obligation of the responsible party and, therefore, are not included in this estimate.

4.4.9 Residuals and Waste Shipping, Handling and Disposal Costs

Disposal costs for contaminated health and safety gear, protective plastic sheeting, and other residuals are assumed to be the obligation of the responsible party (or site owner). They are not included in this estimate.

4.4.10 Analytical Costs

Analytical costs are not included in this estimate. Standard operating procedures for the BSWS do not require sampling and analytical activities. The dient may elect, or may be required by local regulatory agencies, to initiate and fund a sampling and analytical program. If specific sampling and monitoring criteria are imposed by local regulatory agencies, the analytical

TABLE 17. EXCAVATION LABOR REQUIREMENTS

Position	Number	Hours per week	Rate $/hour
Excavator operator	1	40	30
Dump truck operator	1	40	30

TABLE 18. BSWS ASSEMBLY LABOR REQUIREMENTS

Position	Number	Hours per week	Rate $/hour
Boom & front-end loader operators	2	42	30
Supervisor/H&S officers	2	42	50
Mechanics	6	42	30

Note: Each person works 6 hrs/day for 7 days.

TABLE 19. OPERATIONS LABOR REQUIREMENTS

Position	Number	Hours per week	Rate ($/hour)
Project Manager/H&S officer	1	40	60
Process Lead Operators	4	42	50
Process Operators	12	42	40
Equipment Operators	4	42	30
Mechanic	1	40	30

requirements could significantly increase the cost of the project.

4.4.11 Facility Modification, Repair, and Replacement Costs

Maintenance labor and material costs vary with the nature of the waste and the performance of the equipment. For estimating purposes, total annual costs of maintenance (labor and materials) are assumed to be 10 percent of annualized equipment costs. Maintenance labor typically accounts for two-thirds the total maintenance costs, as previously discussed in Section 4.4.5. Maintenance material costs are estimated at one-third the total maintenance cost and are prorated to the entire treatment period. Costs for design adjustments, facility modifications, and equipment replacements are included In the maintenance costs.

4.4.12 Site Demobilization and Decontamination Costs

Based on the SITE Program experience, decontamination of mobile equipment and demobilization requires seven days. A boom truck at $5,000/week and a front-end loader at $3,000/week will be rented for one week. Fuel consumption is estimated at four gal/hr. These costs are linked to equipment decontamination and demobilization; transportation is excluded.

Site cleanup and restoration are limited to equipment removal from the site. Requirements regarding the filling, grading, or recompactlon of the soil will vary depending on the future use of the site; they are assumed to be the obligation of the responsible party (or slte owner).

4.5 *RESULTS OF ECONOMIC ANALYSIS*

Table 15 presents the total BSWS treatment cost, at 80 percent online, to be $9.3 million, itemized by cost category. It should be noted that the dollar total does not add up to the total cleanup cost because some cost categories (Le., complete slte preparation, permitting, sampling, analyses, and residuals/waste shipping and disposal) were not included. The disposal cost for the solid waste effluent streams (clarifier residue/dewatered sludge, casing chips and metallic lead fraction) represents about 85 percent of the treatment costs. The next largest cost components are labor (12 percent) and consumables and supplies (1.5 percent).

Based on 56,362 tons (dry basis) of contaminated soil treated, the total unit cost is $165 per ton. BESCORP believes it Is feasible to develop recycling markets for casing chips and the metallic-lead fraction, which would further reduce treatment costs. However, at this time, the recycling markets have not materialized.

4.6 REFERENCES

1. Evans, G.E. "Estimating lnnovative Technology Costs for the SITE Program." EPA/RREL **for** Journal ***of Air Waste Management Association.*** July 1990. Volume 40, No. 7.

2. Peters, M.S. and K.D. Timmerhaus. ***Plant Design and Economics for Chemical Engineers.*** Third Edition. McGraw-Hill, Inc., New York. 1980.

Appendix A
Process Description

A.1 INTRODUCTION

General

Previous treatability tests indicate that the BSWS, a continuous flow process, can remove metals such as lead, lead compounds, and certain radioactive waste from coarse/sandy soil through a combination of trommel agitation, high-pressure washing, density separation, and particle-size segregation. Typically, the heavy metals concentrate in the fines fraction (less than 150 mesh), a small portion of the original soil, thus reducing the volume of material requiring disposal or further treatment. The BSWS effectively separates washed coarse/sandy soil particles from the fines. Contaminant solubility in the process water can be a significant factor both in contaminant distribution and wastewater treatment. The arrangement and operation of the process will depend on site contaminant(s) characteristics.

ABE Site

The contamination at the ABE Site was primarily metallic lead and lead compounds from broken batteries found in a gravelly/sandy soil. The soil was a heterogeneous feedstock that contained large pieces of battery casings. various size pieces of metallic-lead battery posts, battery casing chips, together with fine particles of lead and lead compounds.

For the SITE Demonstration, the soil was prescreened from material that would not pass a 21/2 x 21/2" square grating, eliminatlng some rocks and the large battery casings. Previous tests by BESCORP indicated water (no additives) was sufficient as the washing medium. A mobile 20-tph unit was used to perform this SITE Demonstration, though flow rates for the test runs were significantly below 20 tph, at 2.4 to 4.2 tph, due to flow limitations (bottleneck) In the casing chip separator.

A.2 PROCESS DESCRIPTION

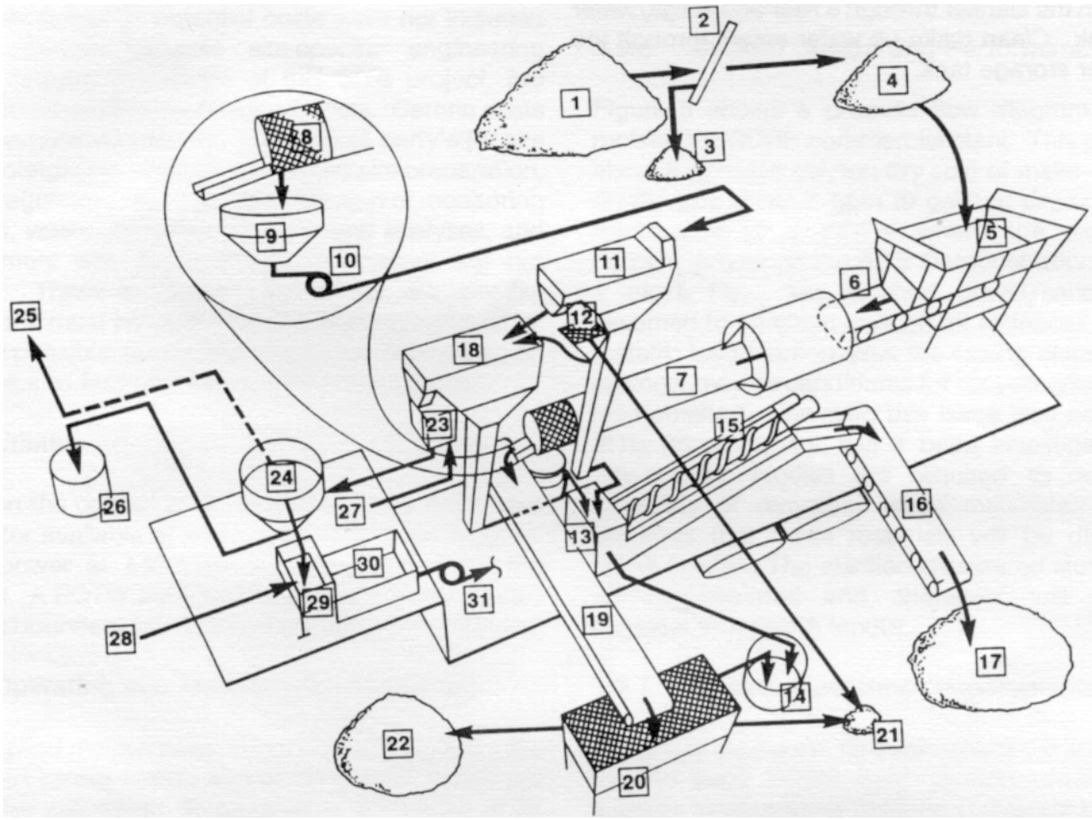
Figure A-1 presents an isometric flow diagram of the BSWS SITE Demonstration. A more detailed flow diagram with sampling points and mass balance streams is presented in Appendix C, Figure C-2. A modified commercial-scale flow dhgram Is presented In Section 4.

Contaminated soil, screened from battery casings and consisting of particles less than 2½" in diameter, falls from a hopper to a conveyor that feeds the revolving trommel wash unit. The washer breaks the soil apart through deagglomeration and attrition washing.

Soil ranging from minus 2½" to plus ¼" diameter (gravel fraction) passes from a drum screen to a conveyor, which ends at a casing chip separator that removes battery casing chips from the gravel. This unit also takes out any heavy metallic-lead particles, which then fall into a drum for recycling. The washed gravel is stockpiled.

Material smaller than ¼" passes through the drum screen into a slurry tank from which the slurry is pumped into the first counter-flow separation chamber. The small casing chips (less than ¼"), separated from the soil by a 10-mesh screen, travel to the chip pile. The fine slurry flows through the lo-mesh screen and passes to the second counter-flow separator for further particle size separation.

The minus ¼" to plus 150 mesh soil particles (sand fraction) recovered from the two separators pass over a density separator. This device removes discrete, metallic-lead particles, which are stored in drums with the larger particles of metallic lead from the chip separator. The remaining soil enters a dewatering spiral classifier where the washed sand exits on a conveyor to a washed sand stockpile.



No.	Description	No.	Description	No.	Description
1	Excavated soil	12	Screen -10 mesh	22	Washed gravel stockpile (-2½" to +¼")
2	Debris screen -2½"	13	Density separator	23	Coagulation mix chamber
3	Battery casings and debris	14	Heavy metal fraction (Pb) drum	24	Clarifier
4	Screened feed pile (-2½" to +0)	15	Dewatering spiral classifier	25	Liquid discharge to POTW
5	Feed hopper	16	Product conveyor	26	Sludge drum
6	Feed conveyor	17	Washed sand pile (-¼" to +150 mesh)	27	Coagulation drum and pump system
7	Trommel wash unit	18	Separation chamber No. 2	28	Make-up water
8	Drum screen	19	Product conveyor	29	Filter and surge/water storage tank
9	Slurry tank	20	Casing chip separator	30	Clean water tank
10	Slurry pump	21	Washed casing chips (-2½" to 10 mesh)	31	Water circulation pump
11	Separation chamber No. 1				

Figure A-I. BESCORP Soil Washing System (isometric drawing).

The finest particles, small enough to pass through a 150-mesh screen, mix with a coagulant and enter a clarifier. There they form a dense sludge. which is discharged to waste storage drums for proper disposal at an EPA-approved landfill. The liquid recycles in the system from the clarifier through a filter and surge/water storage tank. Clean make-up water enters through the surge/water storage tank.

Appendix B
Vendor's Claims for the BESCORP Soil Washing System

B.1 INTRODUCTION

The concept of reducing the volume of soil contaminated with chemicals is based on the tendency of many organic and inorganic contaminants to bind chemically or physically to clay and silt partides. These particles may attach to larger soil particles (sand and gravel) through chemical precipitation that coats particles, or through physical processes such as adsorption, absorption. or compaction of soil mass (agglomeration).

B.2 TECHNOLOGY DESCRIPTION

The BESCORP Soil Washing System (BSWS) is a water-based process for mechanically scrubbing excavated soils. The process uses a variety of treatment methods, depending on the contaminant type(s), as follows:

- Particle size separation:
  -- Concentration of contaminants with the fine soil fraction
- Gravity separation:
  Liberation and removal of dense or light particulate contaminants
- Attrition scrubbing:
  _ Liberation of chemical coatings (such as $PbSO_4$) from soil particles
- Contaminant dissdution in the wash solution:
  -- Partitioning contaminants to the wash solution, and removing them in the wastewater treatment system

Figure B-l depicts a simplified block flow diagram of the BSWS, which can vary based on the characteristics of both the soil and the contaminant(s). In addition, the approach can vary depending on whether a physical volume-reduction process (resulting in a smaller volume of more contaminated material) Is requested, or if total remediation of the site material Is specified.

B.3 CLAIMS

BESCORP can separate soils and contaminants by virtue of the size and density character of each, based on physical principles and treatability tests that BESCORP has performed.

1 The BSWS can segregate fine material from the coarse material, alter the "size" cut within minutes, and produce a coarse fraction that is free from undersize. This is a very important capability because the fines very often are the contaminants, or are very contaminated. The ability to produce the oversize free from fines is not easily achievable with other sizing devices such as hydrocyclones or sand screws.

2. The BSWS can recover material from the soils based on the density of the contaminant as well as the particle size so it can recover the dense metals as well as light material that might be contaminated (such as the battery casings that are permeated with lead).

3. The BSWS can remove contaminated surface coatings from soil, sand, and gravel particles, thus moving the contamination from the oversize to the fine fraction.

The above processes are able to provide a washed sand and gravel fraction (21/2 in x 150 mesh) that is suitable for placement back on-site in many instances. In other cases, it will be necessary to provide post-treatment to complete remediation. The BSWS process provides a more amenable material for post-treatment. Soil fractions can be processed through a series of steps optimized for each individual feed requirement.

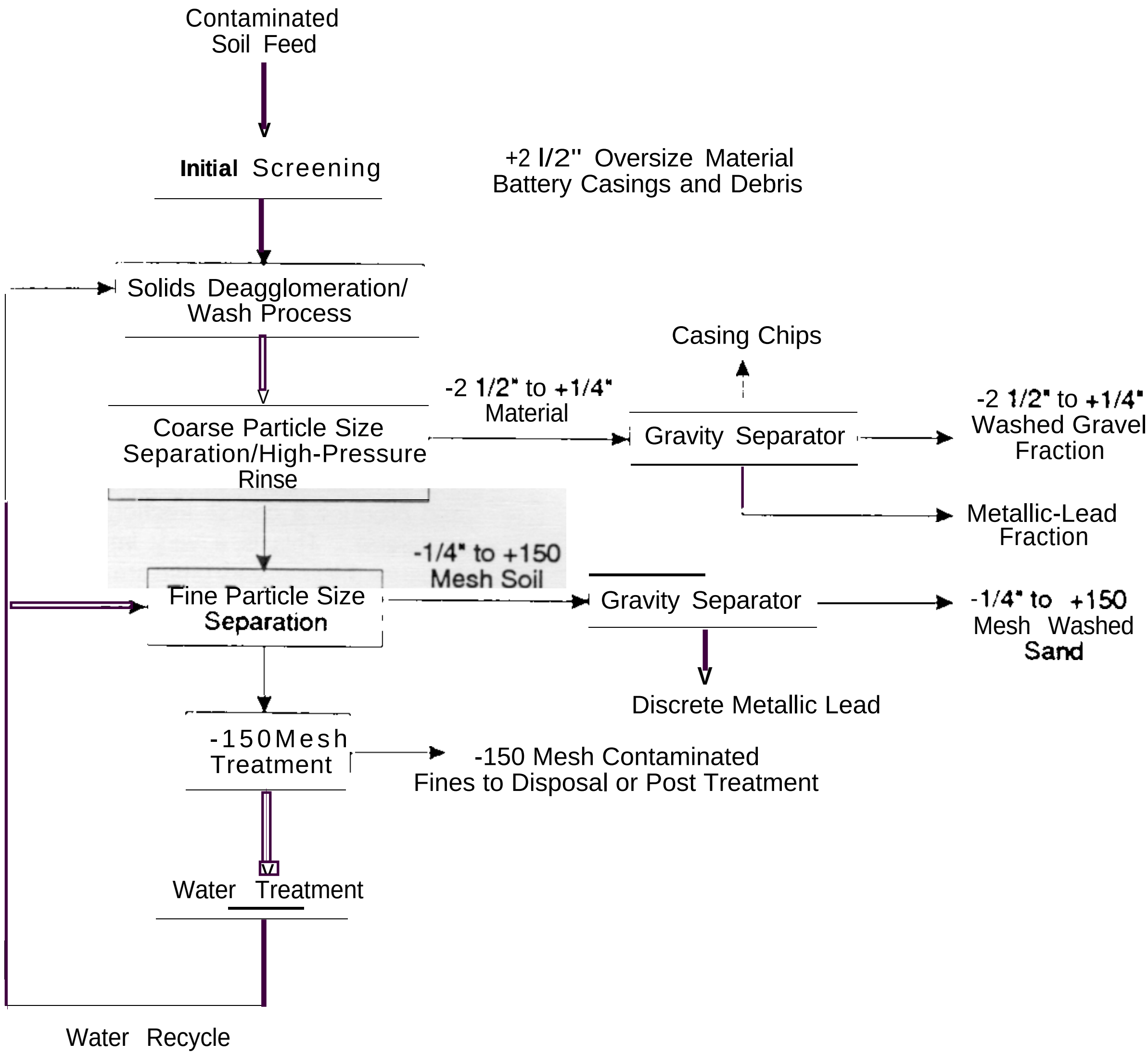


Figure B-1. BESCORP block **flow diagram.**

B.4 DESCRIPTION OF DEMONSTRATION CONDITIONS

Soil washing is a flexible processing approach for contaminated soil volume reduction. This flexibility can only be utilized when the material has been properly evaluated through effective sample collection and site assessment. The proper configuration of the plant Is dependent on the lab evaluation of the material at the site. as represented by the remedial investigation and treatability samples provided to the soil washing contractor. This must be determined before the plant can be built or modified for that particular application. If the sampling program that generates the samples and/or data that are used to design the plant is In error, then the plant performance will be compromised.

The BESCORP participation In the EPA SITE Demonstration Program provided an opportunity to operate the BSWS with very concentrated oversight on the application of the plant to a contaminated material that was perfect for a size-separation-only process. This was the concept until the site was excavated for the material to be processed.

The excavated material was observed to be dramatically different from the ABE Treatability Study samples (Appendix D Case D.lO). There were nearly whole battery casings and every size smaller; there were metallic lead pieces as large as 5-pound battery buses. BESCORP immediately realized that the plant would not be able to provide a passing product. As mentioned elsewhere, the plant was modlfied to remove dense metallic lead in every imaginable size and configuration, and to remove every size casing particle from half casings down, in both ebonite and polyethylene. BESCORP made best estimate projections from the evaluation of this material as to the split required at 150 mesh to provide a clean sand fraction. After the shakedown period, BESCORP felt that they were within the deslgn envelope for this material to process through the BSWS plant and meet the redeposit goals; however. subsequent SITE test data revealed that the sand cut should have been set at 80 mesh.

After the first run through the plant. no further alterations were allowed under the SITE Program oversight, as the three runs needed to be consistent to measure plant performance. The weather allowed only marginal operating temperatures for the plant; freezing temperatures prevented processing of all the material stockpiled on-site. BESCORP was able to complete the test runs and began decontamination of the plant with 6 inches of snow on the ground and many components frozen. No attempt to rerun the tests was possible at that point.

B.5 BSWS MODIFIED COMMERCIAL UNIT FOR ABE-TYPE LEAD REMOVAL

As discussed in Appendix C, the SITE analytical data in Tables C-l and C-3 indicate that the BSWS is effective In removing lead from the minus ¼" to plus 10 mesh fraction of the feed soil to produce a corresponding fraction of washed sand that meets the cleanup goals. The minus 10 mesh to plus 156 mesh sand fraction will not meet the established EPA goals due to the presence of excessive contaminated flnes. Therefore, the washed sand fraction (that will meet EPA goals) must be cut somewhere between 10 and 150 mesh to maximize the quantity of material that meets these goals.

Based on recent bench-scale tests in Table B-l, BESCORP claims that the addition of an attrition scrubber plus size separation (at plus 66 mesh) in a third separation chamber will produce a minus ¼" to plus 66 mesh sand fraction that will meet these goals (these equipment kerns are discussed below). From these data, BESCORP projects the following process efficiencies for the three Demonstration runs: 76, 67, and 69 percent, respectively. This has not yet been demonstrated by the BSWS unit.

To upgrade the BESCORP unit to a full commercial size, and to achieve the performance objectives. the fdlowing equipment items are included in Figure 3:

- Performance Objective: Remove large battery casings from soil.

  A 21/2" vibrating screen unit is included. This item was used at ABE but was not within the scope of the BSWS SITE Demonstration unit.

- Performance Objective: Clean sand to meet EPA cleanup goals.

  Downstream of the density separator, add an attrition scrubber that contains slurry agitation cells in series, each with a large variable speed agitator.

  Downstream of the attrition scrubber, add a third separation chamber that produces a minus ¼" to plus 80 mesh sand fraction.

TABLE B-l. BESCORP ATTRITION WASHING AND SCREENING
Vendor Bench-Scale Data*

Run	Bench test	-1/4" to +80 mesh sand fraction		
		Dry wt.% of total sand fraction	Total Pb mg/kg	Pb, TCLP mg/L
1	1-5	83.3	98	1.2
1	1-C	88.4	270	3.9
Average		85.9	184	2.6
2	2-7	91.8	390	4.1
2	2-C	87.9	185	4.6
Average		89.9	288	4.4
3	3-1	84.2	225	2.5
Average		84.2	225	2.5

*Data not validated under SITE Program

. Performance Objective: Reduce water loss in clarifier sludge.

Add a rotary vacuum sludge filter to reduce the water loss. Filter vendor claims ABE sludge could achieve 80 to 85 percent dry solids content.

Appendix C
SITE Demonstration Results

C. 1 INTRODUCTION

The goal of this SITE Demonstration was to determine the effectiveness of the BSWS in remediating lead-contaminated soil at a lead battery site. ABE was selected as a representative site on the basis of a Remedial Investigation (RI) and the site's inclusion on the NPL (Figure C-l) in 1989. SITE Demonstrations emphasize meeting the EPA cleanup levels (and/or ARARs) for the hazardous contaminant(s) present.

The established EPA cleanup levels for redeposit of the ABE Site soil were less than l,000 mg/kg total lead and less than 5 mg/L TCLP lead. Soil excavations at three different locations resulted in three marginally different feed soil analyses.

The primary objectives of the BSWS SITE Demonstration consisted of the following:

- Assess the ability of the process to comply with EPA's lead cleanup goals for redeposit of washed soil at the site;

- Determine if the BSWS can achieve greater than 75 percent process efficiency by washing sufficient percentages of contaminated gravel and sand to the levels suitable for redeposit;

- Develop economic data for the BSWS.

Secondary objectives were as follows:

- Determine if the washed battery casing chips meet the cleanup goals;

- Evaluate the BSWS reliability;

- Document the operating conditions of the BSWS for application to other hazardous waste sites.

The RI analytical data plus initial treatability tests (Appendix D) performed by BESCORP in 1991 on ABE soil samples (used for the RI analyses) indicated that the site was Meal for the BSWS because lead contamination consisted primarily of fine particles (minus 150 mesh) in a gravelly/sandy soil. However, feed soil excavated for the Demonstration differed significantly from the RI samples due to sizable quantities of whde battery casings. casing chips, and metallic lead discovered in the soil, plus contamination of a portion of the sand fraction above 150 mesh. BESCORP modified their system to remove these materials by adding a casing chip separator and a density separator. Whde battery casings were eliminated with a **2½"** screen prior to the Demonstration runs.

A portable BSWS unit with a design capacity of 20 tph was used to evaluate the process effectiveness. The original BSWS, built to process 20 tph of soil when removing silt and clay from uncontaminated sandy soil, was a water-based, vdume-reduction unit that used agitation, attrltionscrubbing, high pressurewashing, and particle size separation. This system was modified to remove lead, lead compounds, and battery casing chips through the addition of a density separator and a casing chip separator. The modified system capacity is about 5 tph, primarily due to restricted flow in the casing chip separator.

The BSWS was demonstrated at the ABE Site in August 1992. About 46 tons of soil contaminated with broken lead batteries were treated during the program. The Demonstration included a series of shakedown tests and three test runs. Prior to initial system startup, the EPA and the SITE contractor (FWEI) reviewed the final Demonstration Test Plan (including the approved Quality Assurance Project Plan) with BESCORP personnel [l]. Pilot plant shakedown and blank runs started the first week in August and continued for three weeks. During this time. a field audit was made by S-Cubed, Inc. for the EPA.

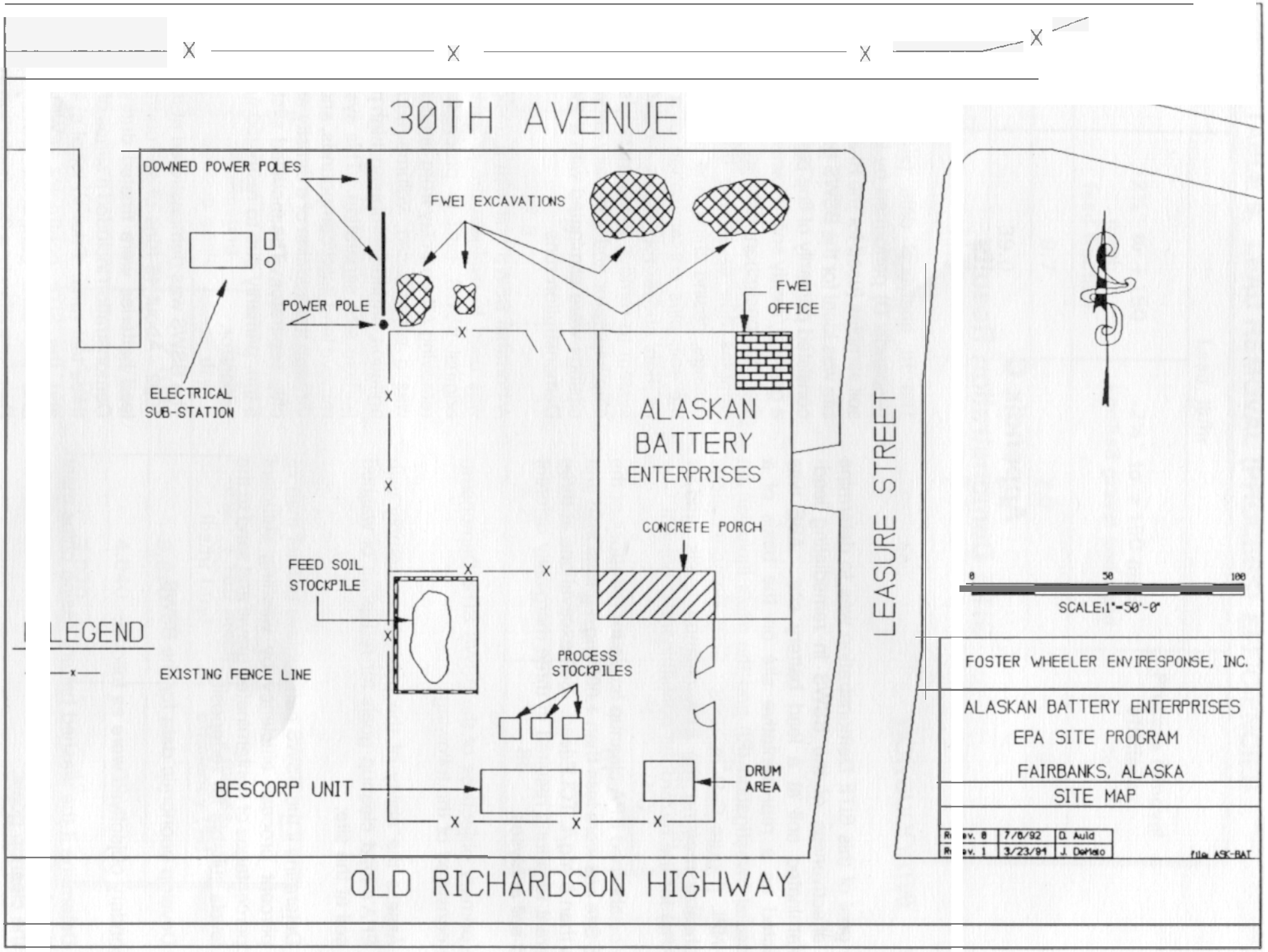


Figure C-1. ABE site map.

The three SITE test runs were conducted during the last two weeks in August.

C.2 SOIL WASHER PERFORMANCE

C.2.1 Overview

Figure C-2 presents a detailed flow diagram of the BSWS SITE Demonstration Unit with identification and location of sample points and mass balance streams. Process stream characterization and associated statistical data are presented in Tables C-l and C-2. The detailed mass balances for the three test runs are shown in Table C-3. Appendix A contains a description of the process. Figure C-3 presents the plant layout.

Total Lead

Figures C-4, C-5, and C-6 plot the total lead concentration In the feed soil (SS1), washed gravel (SS2), and sand fractions (SS3) as a function of total lapsed time for the three Demonstration runs. In Run 1, three gravel samples contained discrete pieces of metallic lead due to improper operation of the casing chip separator. Minor equipment adjustments, made to this separator after Run 1. Improved metallic lead removal. By Run 3, no metallic lead was present in the washed gravel. With the improved metallic lead removal, the washed gravel easily met the EPA goals for both total lead and TCLP (Figures C-6 and C-7).

Effect of Metallic Lead on Heterogeneity

The presence of metallic lead particles was the largest contributing factor in producing heterogeneous lead removal data. Table C-2 summarizes the total lead and TCLP measurements for both the untreated feed soil and the treated gravel and sand fractions. Samples that contained visible metallic lead particles had much higher lead content and much greater variability (heterogeneity) than the samples where ***no*** visible metallic lead was detected. This effect was most obvious in the gravel fraction, where both the average total lead content and the standard deviation are two orders of magnitude greater for samples with visible metallic lead. The bimodal population containing visible metallic lead and no visible metallic lead indicates the importance of efficiently removing the metallic lead from the gravel fraction. The sand fraction contained no visible metallic lead.

Total Lead and TCLP Profiles

The total lead and TCLP concentration profiles of the washed sand fractions did not meet EPA goals in any of the three runs (Figures C-4, C-5, C-6, and C-7) because the sand fraction was Improperly sized due to the presence of excessively contaminated fines. This conclusion is substantiated by the data presented In Tables C-l and C-4 (Lead Partitioning). Table C-1 indicates that the washed composite sand fraction (SS3), consisting of minus ¼" to plus 150 mesh material, failed both TCLP lead (42, 40, and 26 mg/L) and total lead (1,808, 1.670, and 1,609 mg/kg) cleanup goals. However, if the washed materlal is split into a coarse (minus ¼" to plus 10 mesh) and a fine (minus 10 to plus 150 mesh) fraction, the coarse sand fraction meets the EPA goals, with the exception of one TCLP measurement that slightly exceeded the TCLP goal. The sand fines fraction (minus 10 mesh to plus 150 mesh) failed to meet the EPA goals. Appendix B discussed modifications to the BSWS unit in washing the sand to improve operation for a commercial unit,

C.2.2 Process Monitoring and Control

Mass Balances

Washed gravel (Stream 2, Figure C-2) and sand (Stream 3) were weighed on a truck scale at about lo-minute fill times (45 to 60-minute intervals) to develop flow rate data. The feed soil (Stream 1) was also weighed by truck scale and dumped into the feed hopper by a front-end loader on a fairly consistent, although intermittent, batch basis-as presented In Figures C-6, C-9. and C-10. These figures show the total lapsed time for each run including shutdowns.

The feed flow ***rate*** to the trommel washer (Stream 1A) was contrdled by the combination of variable speed of the conveyor and adjustable discharge port opening. Feed rate was calibrated before each test run. The mass balance flow rates in Table C-3 represent the average rates calculated over the actual operating time of the unit (excluding downtime). Clarifier sludge (Stream 4) was cdlected in drums, at a fairly uniform rate. When filled, these drums were immediately sampled with a Coliwasa tube to obtain a representative sample (SS4). The drums were weighed and analyzed at the end of a run. The total sludge weight was then divided by the operating hours to develop the average

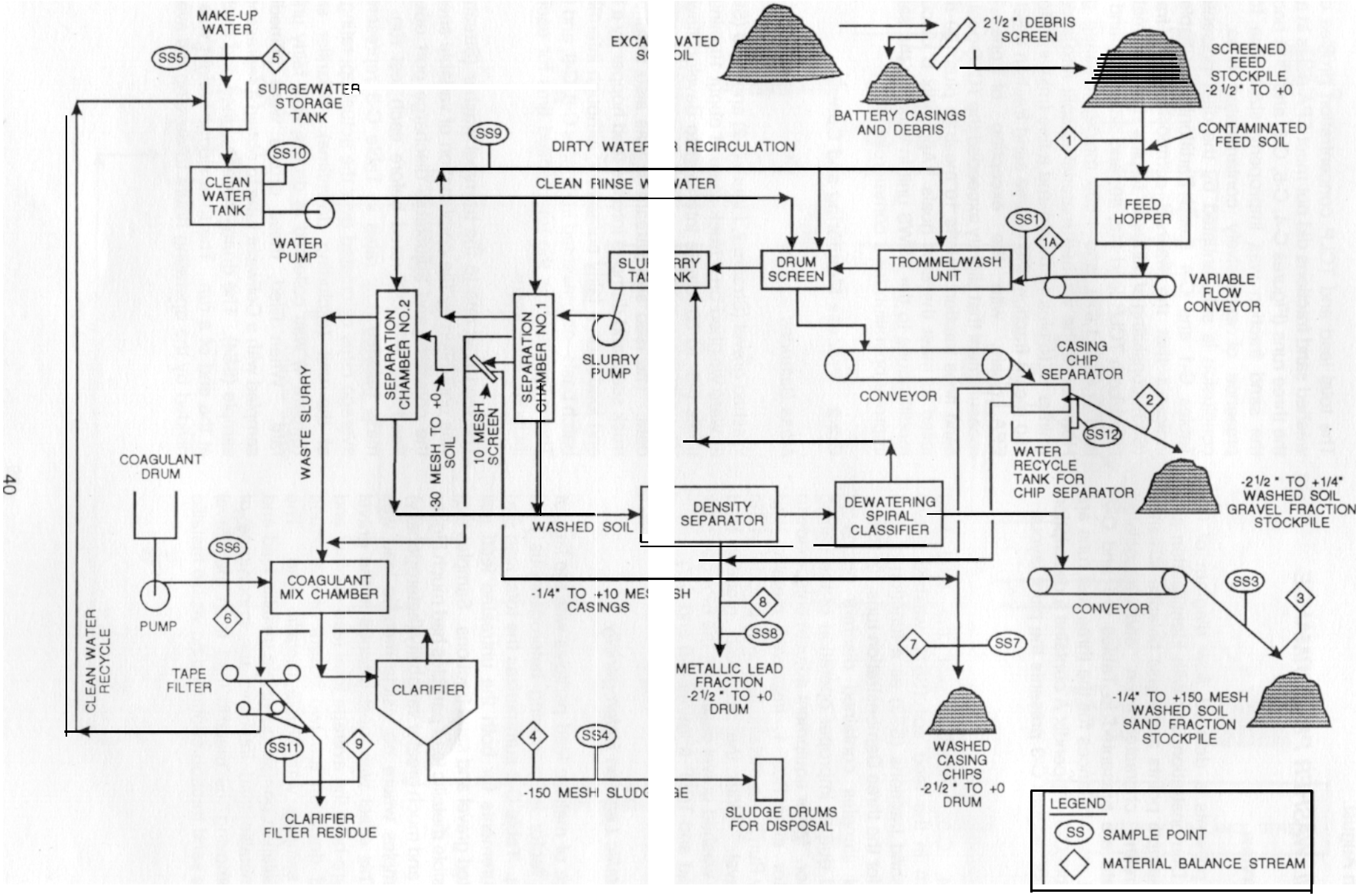


Figure C-2. Detailed BSWS flow diagram for SITE demonstration.

TABLE C-1
KEY PROCESS STREAM CHARACTERIZATION DATA

Stream 1A feed soil average SS1 analysis	Casing chips wt % dry	Total moist wt %	pH	Soil fraction – modified lead digestion without grinding: 2.5 to 1/4" mesh Pb mg/kg	2.5 to 1/4" mesh Wt % dry	1/4" to 10 mesh Pb mg/kg	1/4" to 10 mesh Wt % dry	10 to 150 mesh Pb mg/kg	10 to 150 mesh Wt % dry	< 150 mesh Pb mg/kg	< 150 mesh Wt % dry	Composite Pb mg/kg	Pb TCLP mg/L
Run 1*	6.0	7.3	6.6	1,080	57.2	3,650	7.8	5,670	23.9	17,700	11.0	4,210	72
Run 2*	5.0	7.1	6.7	11,600	48.1	8,900	9.5	6,840	31.3	16,000	11.3	10,400	132
Run 3*	1.7	5.3	7.1	497	45.1	824	9.7	3,340	35.7	8,210	9.5	2,280	50

Stream 2 gravel average SS2 analysis	Casing chips wt % dry	Total moist. wt%	pH	2.4 to 1/4" mesh wt% dry	1/4" to 150 mesh wt% dry	<150 mesh wt% dry	Composite Pb mg/kg	Pb TCLP mg/L
Run 1*	0.4	1.7	7.2	98.3	1.7	0.02	2,540	1.0
Run 2*	0.0	1.3	7.0	96.9	1.1	0.04	903	0.8
Run 3*	1.2	3.9	6.7	96.3	1.6	0.04	15	0.2

Stream 3 sand average SS3 analysis	Casing chips wt % dry	Total moist. wt%	pH	Soil fraction – modified lead digestion without grinding: 1/4" to 10 mesh Pb mg/kg	1/4" to 10 mesh Pb, TCLP mg/L	1/4" to 10 mesh Wt% dry	<10 mesh Pb mg/kg	<10 mesh Wt% dry	<150 mesh Wt% dry	Composite Pb mg/kg	Pb TCLP mg/L
Run 1*	0.0	11.7	6.3	191	4.8	44.3	3,110	55.7	0.5	1,810	42
Run 2*	0.0	11.4	6.4	162	5.7	43.7	2,820	56.3	1.0	1,670	40
Run 3*	0.0	12.7	6.6	69	1.7	38.3	2,400	61.7	1.3	1,510	26

* Run 1 – average of 7 data points
Run 2 – average of 9 data points
Run 3 – average of 8 data points

TABLE C-2. STATISTICAL SUMMARY OF LEAD IN FEED SOIL, GRAVEL AND SAND FRACTIONS

Run	Metallic lead	Data points	Total lead mg/kg			Pb TCLP mg/L		
			Avg.	Range	Standard deviation	Avg.	Range	Standard deviation
Feed Soil								
1	No	5	2,649	2,293-3,362	400	75	42-170	47.8
	Yes	2	8,318	7,765-8,870	553	63.5	45-82	18.5
	Total	7	4,211	2,293-8,870	2,600	72	42-170	42.0
2	No	4	4,516	3,686-6,590	1,201	156	50-440	164
	Yes	5	14,322	2,911-45,450	14,322	113	48-190	48.2
	Total	9	10,374	2,911-45,450	12,686	132	48-440	117
3	No	7	2,116	951-4,709	1,145	46	26-90	20.3
	Yes	1	3,223	3,223	NA	72	72	NA
	Total	8	2,276	951-4,709	1,132	50	26-90	20.8
Gravel Fraction								
1	No	3	33	32-35	1.4	0.6	0.4-0.7	0.14
	Yes	3	4,423	1,078-9,631	3,167	1.3	1.2-1.6	0.19
	Total	6	2,541	32-9,631	3,283	1.0	0.4-1.6	0.40
2	No	7	26	17-35	6.2	0.8	0.5-1.1	0.20
	Yes	2	3,972	1,302-6,641	2,670	0.9	0.8-1.0	0.10
	Total	9	903	17-6,641	2,067	0.8	0.5-1.1	0.20
3	No	8	15	5-32	8.2	0.2	0.1-0.6	0.15
	Yes	0	NA	NA	NA	NA	NA	NA
	Total	8	15	5-32	8.2	0.2	0.1-0.6	0.15
Sand fraction*								
1	Total	7	1,808	1,449-2,172	256	42	37-48	3.4
2	Total	9	1,670	963-2,477	526	40	30-47	5.0
3	Total	8	1,509	833-1,903	308	26	21-29	3.0

*No metallic lead found in sand fraction.

TABLE C-3

DETAILED MASS BALANCES FOR THE THREE SITE DEMONSTRATION RUNS

Stream	Description	Wet total lbs/hr	Dry total lbs/hr	Water lbs/hr	Lead mg/kg	Lead TCLP mg/L	Lead lbs/hr	Casing chips Wt% dry	Casing chips lbs/hr
	Run 1								
	Streams in								
1A	Feed soil	4,660	4,320	340	4,210	72	18.2	6.0	259
5	Make-up water	1,580	–	1,580	–	–	–	–	–
	Total in	6,240	4,320	1,920	–	–	18.2	–	259
	Streams out								
2	Gravel	2,140	2,100	36	2,540	1.0	5.3	0.4	8.4
3	Sand	1,080	954	126	1,810	42.0	1.7	0.0	0.0
4	Clarifier sludge*	3,340	1,150	2,190	10,500	86	12.1	N/A	–
7	Washed casing chips**	382	357	25	102,000	613	39.0	N/A	–
8	Heavy metal (lead) fraction***	46	44	2	39,000	380	1.7	N/A	–
9	Clarifier filter residue	12	6	7	2,600	N/A	0.02	N/A	–
	Total out	7,000	4,611	2,386	–	–	59.8	–	–
	Total out x 100 = % balance / Total in	112%	107%	124%	–	–	329%	–	–
	Run 2								
	Streams in								
1A	Feed soil	4,950	4,590	351	10,400	132	47.7	5.0	230
5	Make-up water	2,540	–	2,540	–	–	–	–	–
	Total in	7,490	4,590	2,891	–	–	47.7	–	230
	Streams out								
2	Gravel	1,810	1,790	24	903	0.8	1.6	0.0	0.0
3	Sand	1,210	1,070	130	1,670	40.0	1.8	0.0	0.0
4	Clarifier sludge*	3,930	1,290	2,640	8,500	52	10.9	N/A	–
7	Washed casing chips**	333	321	12	102,000	613	32.8	N/A	–
8	Heavy metal (lead) fraction***	60	55	5	39,000	380	2.1	N/A	–
9	Clarifier filter residue	25	8	17	2,100	N/A	0.02	N/A	–
	Total out	7,368	4,534	2,828	–	–	49.2	–	–
	Total out x 100 = % balance / Total in	98%	99%	98%	–	–	103%	–	–
	Run 3								
	Streams in								
1A	Feed soil	8,260	7,830	438	2,280	50	17.8	1.7	133
5	Make-up water	3,410	–	3,410	–	–	–	–	–
	Total in	11,670	7,830	3,848	–	–	17.8	–	133
	Streams out								
2	Gravel	3,540	3,440	82	15	0.2	0.1	1.2	41.3
3	Sand	1,960	1,710	249	1,510	26.0	2.6	0.0	0.0
4	Clarifier sludge*	5,510	1,950	3,560	5,900	60	11.5	N/A	–
7	Washed casing chips**	375	364	11	1,500	36	0.5	N/A	–
8	Heavy metal (lead) fraction***	162	145	17	39,000	380	5.7	N/A	–
9	Clarifier filter residue	64	24	40	850	N/A	0.02	N/A	–
	Total out	11,611	7,633	3,959	–	–	20.4	–	–
	Total out x 100 = % balance / Total in	99%	97%	103%	–	–	115%	–	–

* Unsettled clarifier sludge. This sludge settled/dewatered to about 40 wt% moisture in 48 hours.
** TCLP and total lead analyses were averaged for the first 2 runs (same feed stockpile).
*** TCLP and total lead analyses were averaged over the three runs.
N/A – not analyzed

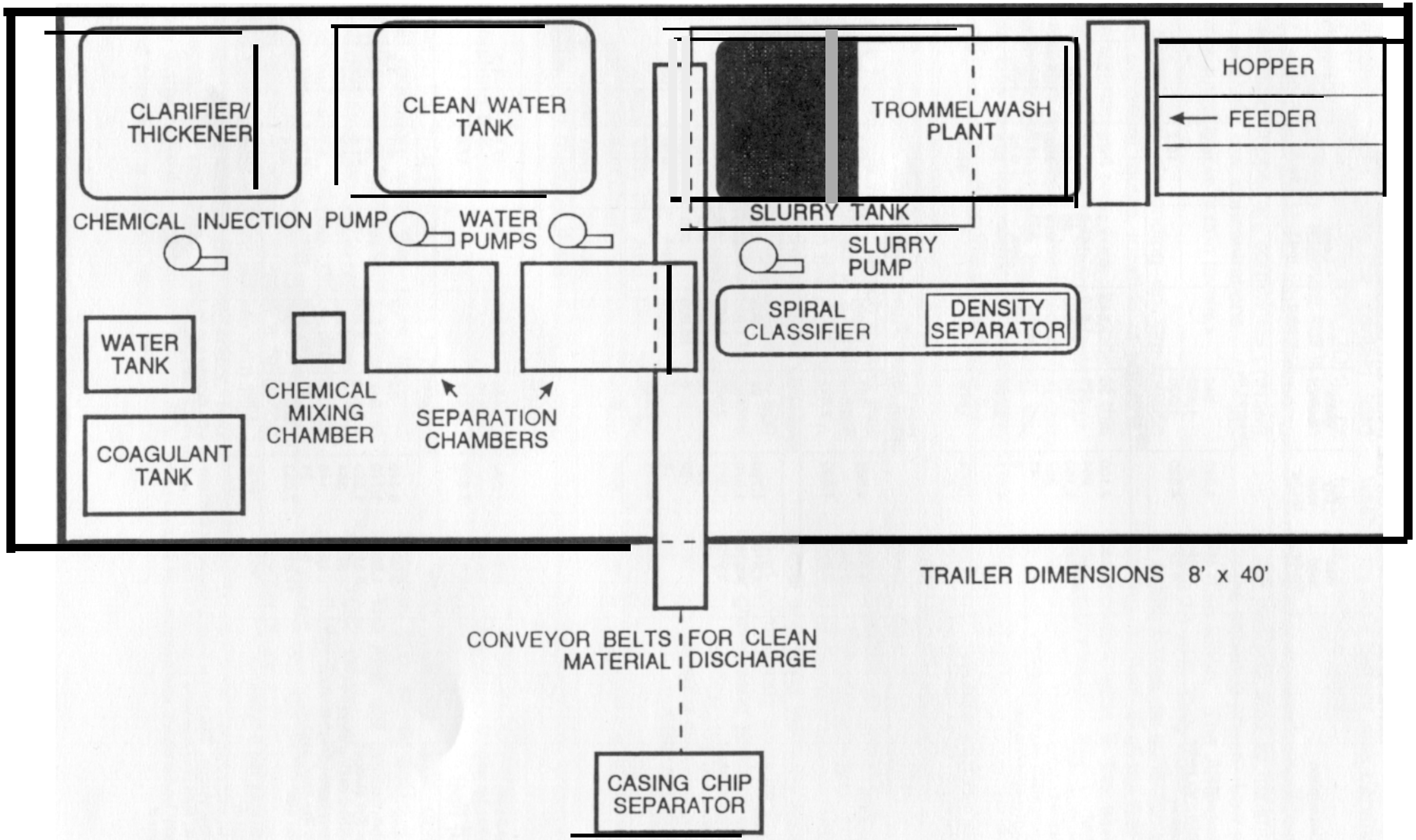


Figure C-3. Plant layout.

Figure C-5
Run 2 - Total Lead Concentration in
Feed Soil and Washed Gravel and Sand

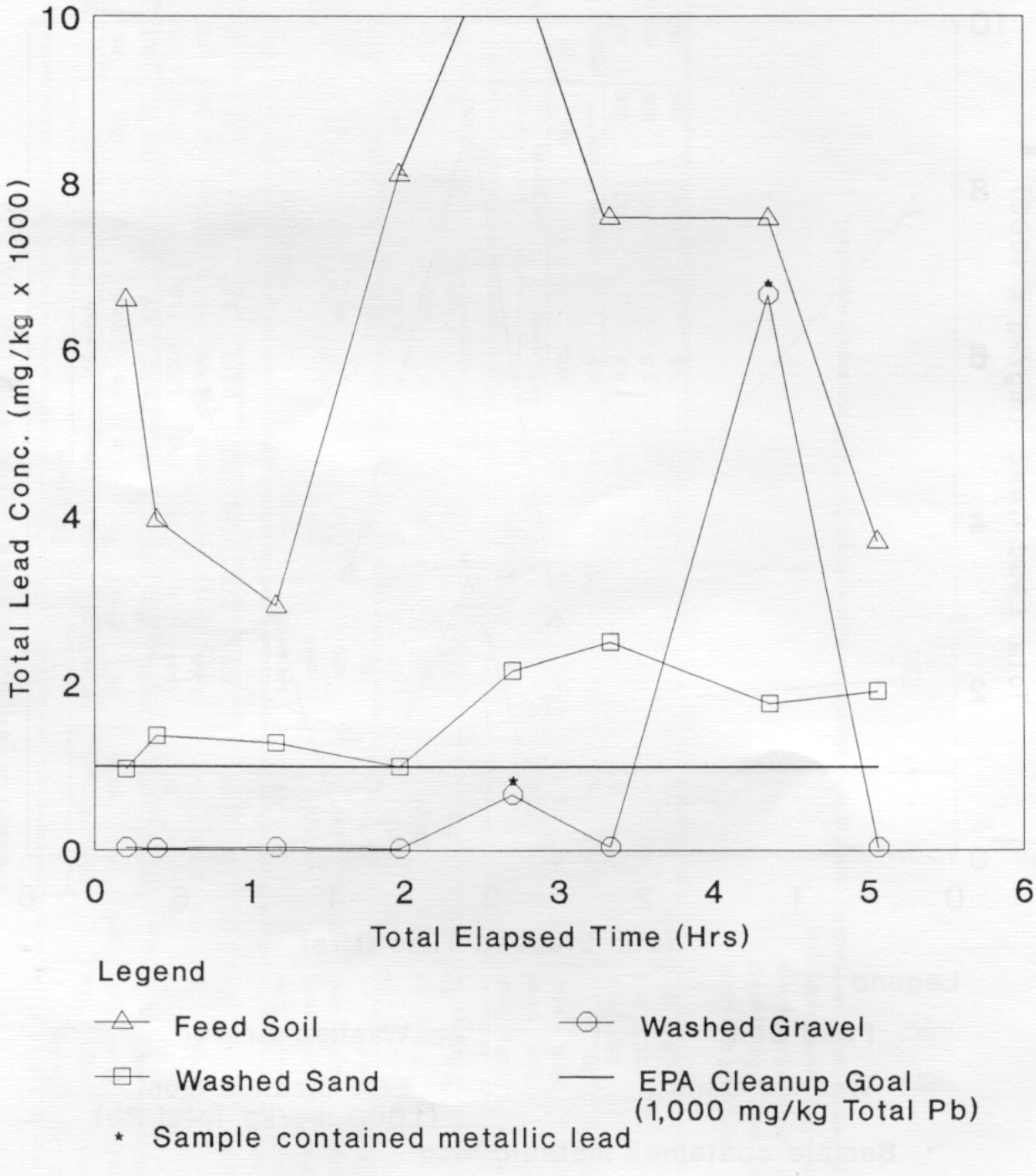


Figure C-6
Run 3 - Total Lead Concentration in Feed Soil and Washed Gravel and Sand

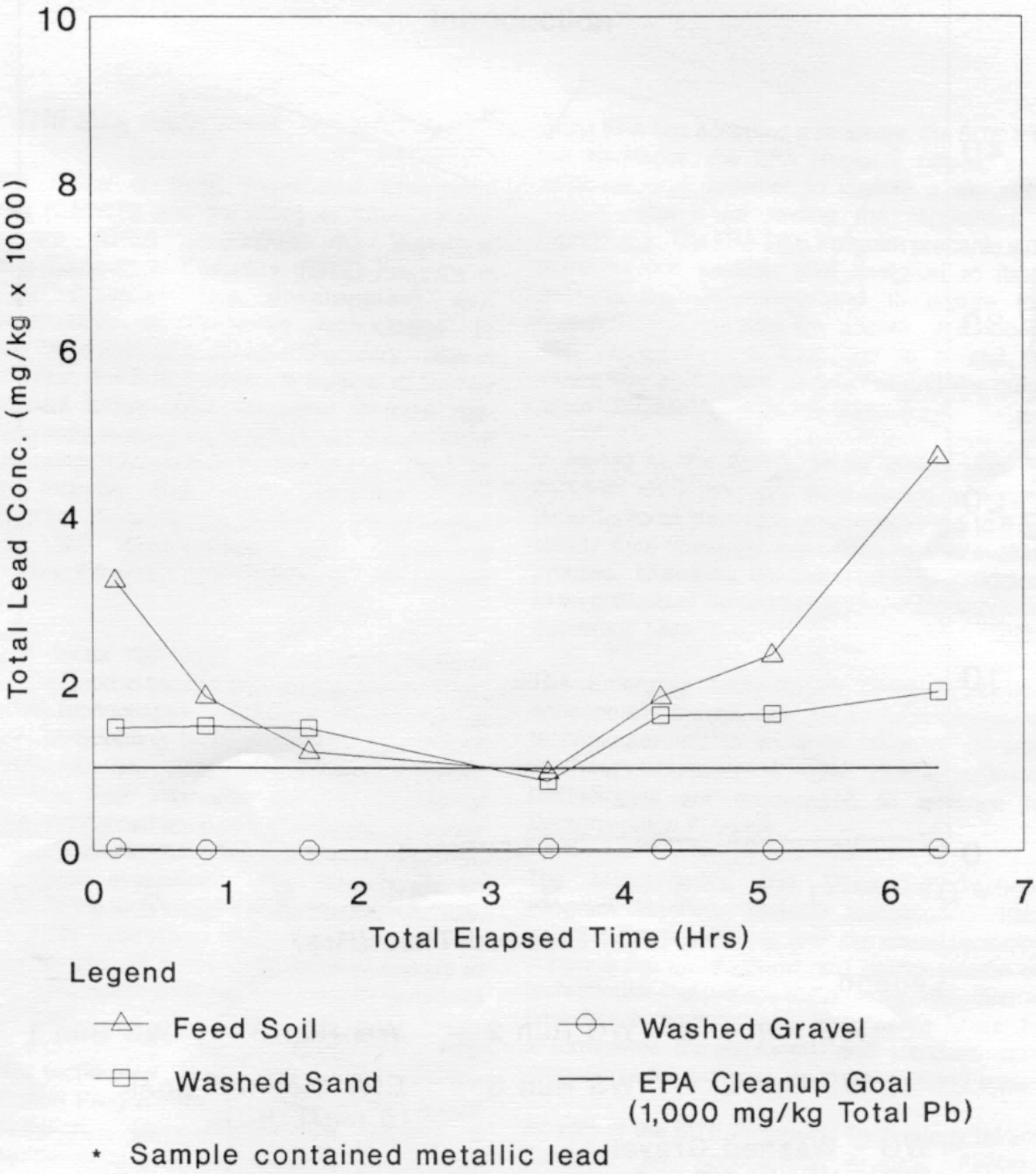


Figure C-7
Lead TCLP in Washed Gravel and Sand

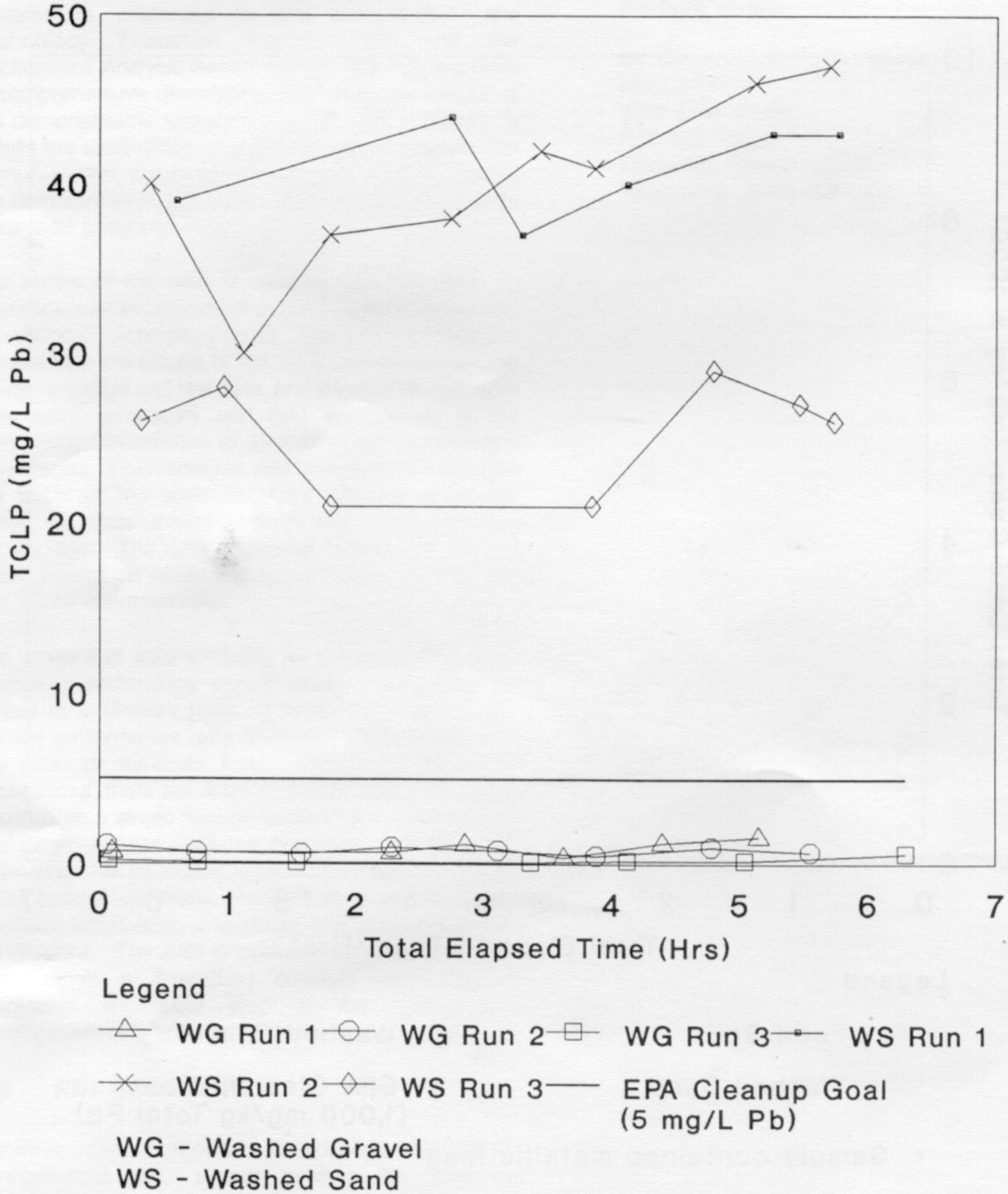


Figure C-8
Run 1 - Solid Stream Flows

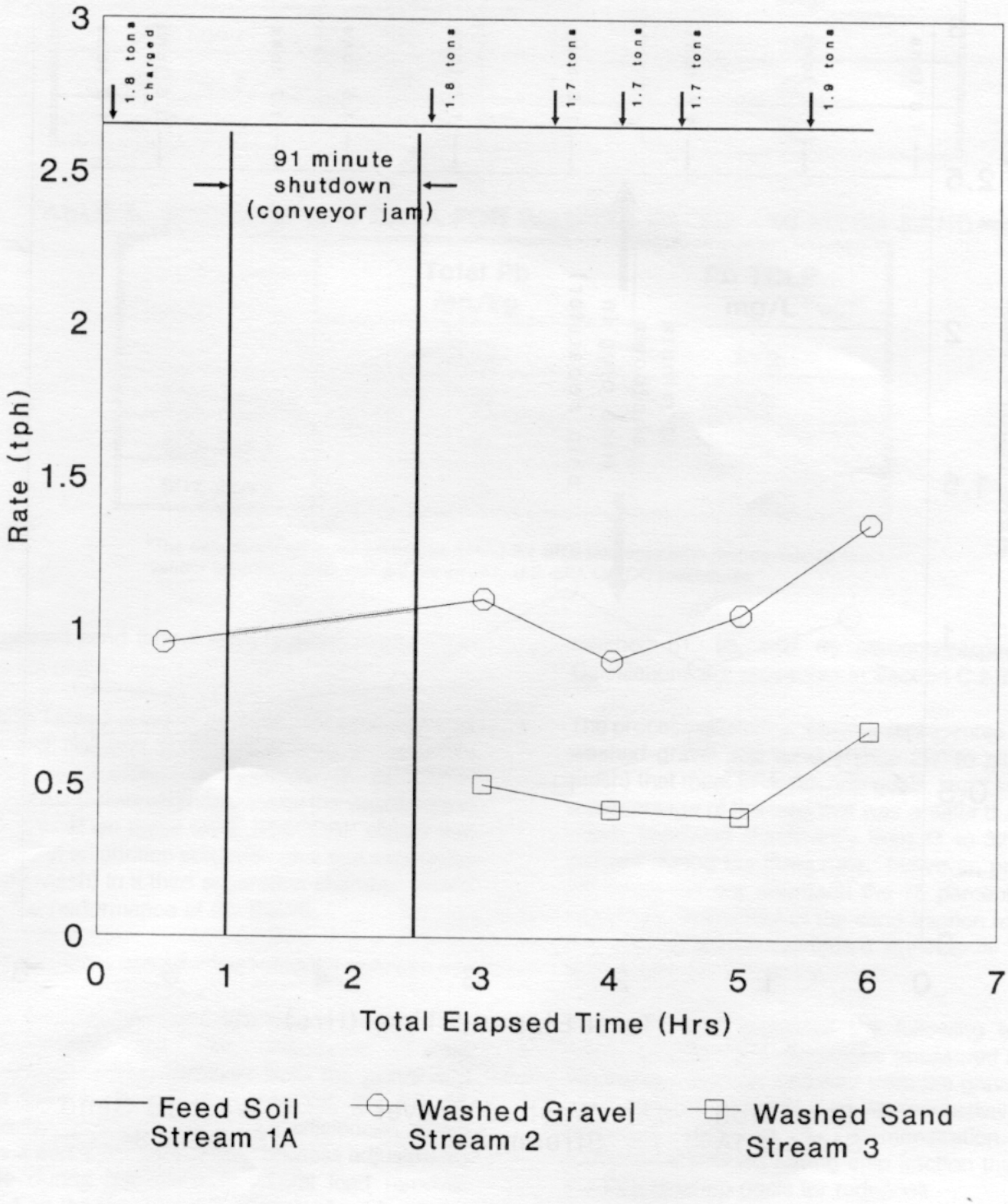


Figure C-9
Run 2 - Solid Stream Flows

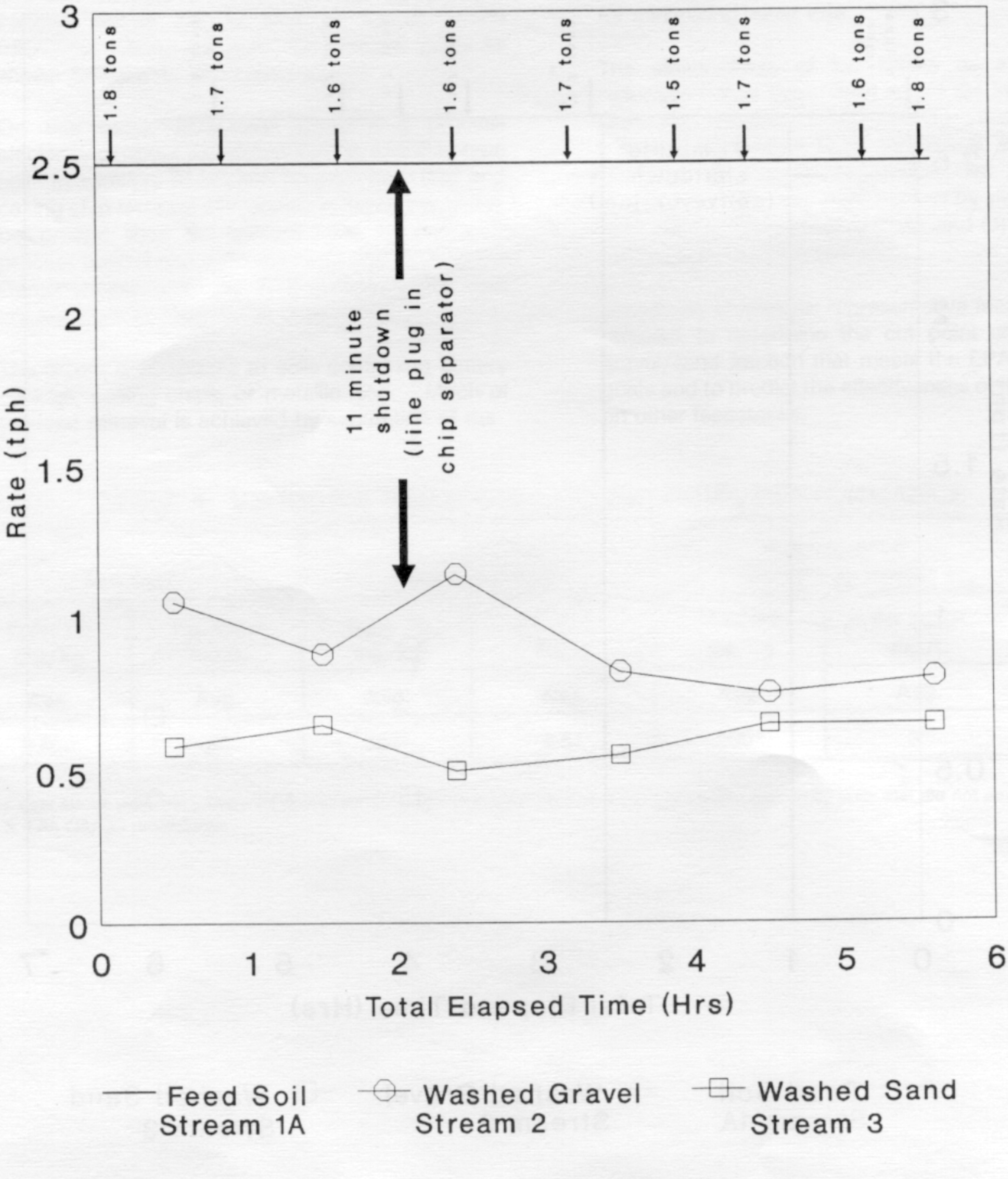


Figure C-10
Run 3 - Solid Stream Flows

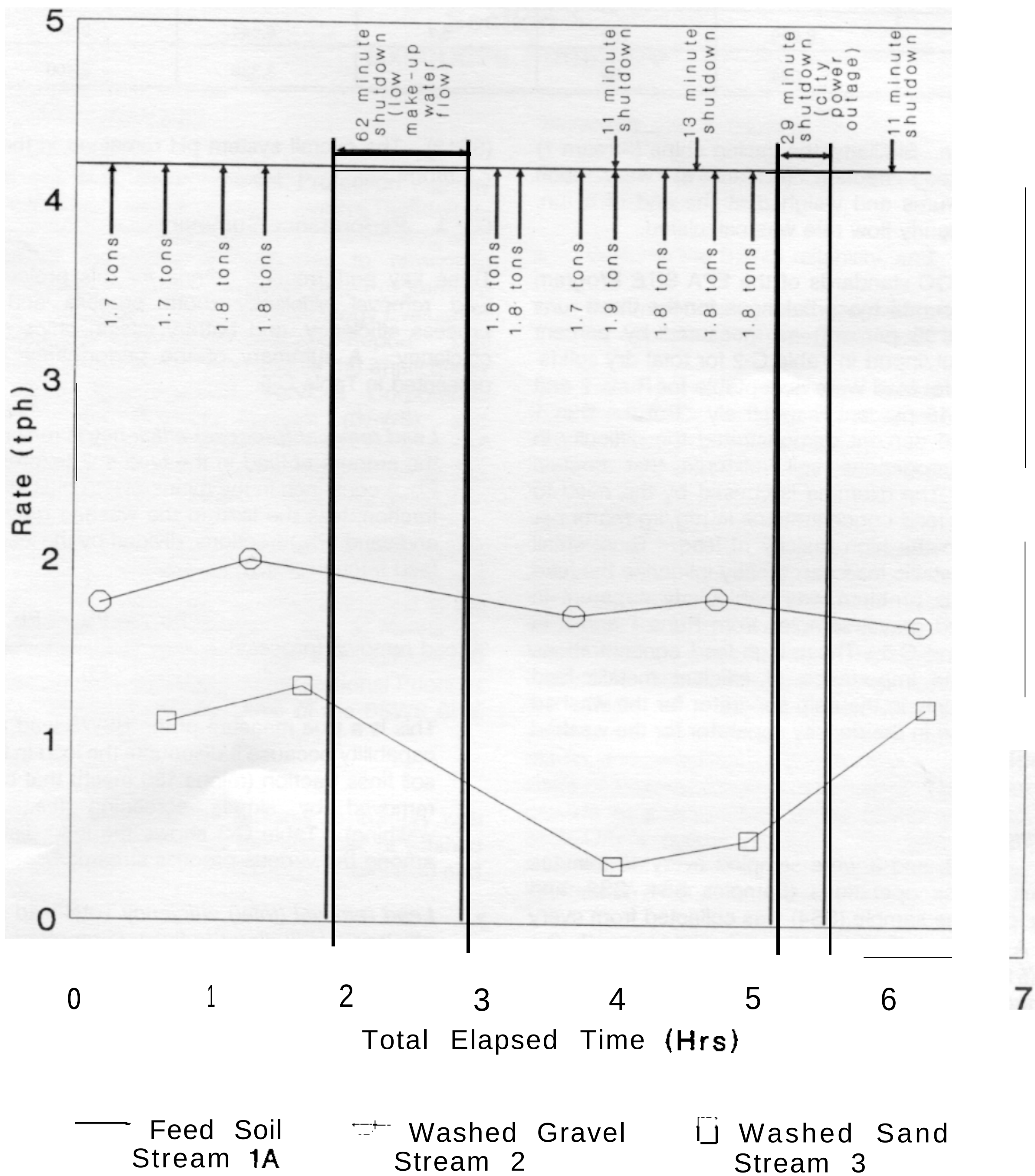


TABLE C-4. LEAD PARTITIONING

	-1/4" to +10 mesh fraction			-10 mesh to +150 mesh	
	Feed soil, SS1	sand fraction Ss3		Feed soil SS1	sand fraction SS3
Run	Pb mg/kg	Pb mg/kg	Pb TCLP	Pb mg/kg	Pb mg/kg
1	3,650	191	4.8	5,671	3,114
2	8,899	162	5.7	6,844	2,822
3	824	69	1.7	3,338	2,403

hourly flow rate. Similarly. the casing chips (Stream 7) and metallic-lead fraction (Stream 6) were each collected in drums and weighed at the end of a run. The average hourly flow rate was calculated.

The high QA/QC standards of the EPA SITE Program resulted in accurate mass balances for the three runs (107. 99. and 96 percent) as measured by percent balance (output/input) in Table C-2 for total dry sdids. The balances for lead were acceptable for Runs 2 and 3: 104 and 115 percent respectively. But the Run 1 balance at 330 percent demonstrated the difficulty in analyzing heterogenous soil mixtures that contain metallic lead. The dilemma is caused by the need to determine low lead concentrations in mg/kg (parts per million) due to the high toxicity of lead. Thus, small amounts of metallic lead can greatly influence the lead analyses. This problem was particularly apparent in several washed gravel samples from Runs 1 and 2 in Figures C-4 and C-5. These high lead concentrations underscore the importance of efficient metallic-lead removal, not only in the chip separator for the washed gravel, but also in the density separator for the washed sand.

Sampling

Streams 1A, 2, and 3 were sampled every 45 minutes during process operations (Samples SSl, SS2, and SS3). A sludge sample (SS4) was collected from every drum (51 drums in Run 3) and cornposited for each run. A composite sampre was collected at the end of each run for casing chips (SS7) and the metallic-lead fraction (SS8).

pH Monitoring

Every 2 hours, a field pH reading was taken of the aqueous streams; dirty water recirculation (SS9). clean water recycle (SSl0). and chip separator recycle water (SS12). The overall system pH remained in the 6.3 to 7.1 range.

C.2.3 Performance Summary

Three key performance criteria for this project were' lead removal efficiency (both process and total), process efficiency, and battery casing chips removal efficiency. A summary of the performance data is presented in Table C-5.

- Lead removal ***(process) efficiency*** is measured as the amount of lead in the feed soil (expressed as Pb_{1A}) contained in the minus 2½" to plus 150 mesh fraction, less the lead in the washed gravel (Pb_2) and sand (Pb_3) fractions, divided by the lead in this feed fraction (Pb_{1A}).

$$\% \text{ lead removal (process)} = \frac{Pb_{1A} - Pb_2 - Pb_3}{Pb_{1A}} \times 100$$

  This is a true measure of the BSWS lead removal capability because it discounts the lead in the feed soil fines fraction (minus 150 mesh) that could be removed by simple screening (i.e., without washing). Table C-3 shows the lead distribution among the various process streams

- Lead removal (total) efficiency. Total lead removal efficiency, including the fines, is reported in Table C-5. This is measured as the total amount of lead in the feed soil (PbT_{1A}) less the lead in the washed gravel (Pb_2) and sand (Pb_3) fractions, divided by the total amount of lead in the feed soil.

$$\% \text{ lead removal (total)} = \frac{PbT_{1A} - Pb_2 - Pb_3}{PbT_{1A}} \times 100$$

TABLE C-5. PERFORMANCE SUMMARY

Form of measurement	Performance achieved %		
	Run 1	Run 2	Run 3
Lead removal efficiency (process + 150 mesh)	28	91	77
Lead removal efficiency (total, including fines)	61	93	65
Process efficiency	11	32	49
Battery casing chips removal efficiency	97	100	70

- Process efficiency represents the amount of the washed gravel fraction plus the sand fraction, expressed as the percent of feed greater than 150 mesh (dry weight basis) that meets the EPA cleanup goals on an hourly-flow basis (totalled for each run cycle). The total lead and TCLP values are averaged for each time interval (for each washed fraction-gravel and sand) to determine the amount of soil that meets these goals.

  In Run 1, only 20 percent of the washed gravel met the cleanup goals. This is equivalent to 11 percent process efficiency. In Run 2, 71 percent of the washed gravel met the goals (32 percent process efficiency). In Run 3, 100 percent of the washed gravel passed (49 percent process efficiency). None of the washed sand from any of the three runs met the cleanup goals (Table C-3). Although the process did not meet the 75 percent target efficiency, performance improved significantly as the Demonstration progressed.

  This approach to process efficiency is very rigorous because it rejects any hourly average analysis of either total lead or TCLP lead that exceeds the cleanup goals. Note that for Run 2, the overall composited average total lead and TCLP analyses for the gravel from Table C-3 are 903 mg/kg and 0.8 mg/L, which meet the cleanup goals. However, Figure C-5 shows excessive total lead concentration in one sample. This causes a reduction in performance for the gravel fraction from 100 percent to 71 percent. On the other hand, this approach eliminates the possibility of the whole run being a failure, if, for example, the overall composited average had been 1,003 mg/kg total lead.

- ***Battery casing chips removal efficiency*** is calculated as the weight percent of chips in the feed soil (C_{1A}) contained in the minus 21/2" to plus 150 mesh fraction, less chips in the washed gravel (C_2) and sand (C_3) fractions, divided by the weight of chips in this feed fraction (C_{1A}), expressed as

$$\%\ \text{casing chips removal} = \frac{C_{1A} - C_2 - C_3}{C_{1A}} \times 100$$

  Table C-3 shows the casing chips distribution among the feed, washed gravel, and sand fractions. No attempt was made to develop an overall casing chip mass balance. Note that the amount of chips in the whole feed was equal to the amount in the minus 2½" to plus 150 mesh fraction because the lab only reported the chips that could be manually removed from a sample aliquot (i.e., down to about 10 mesh). As expected none of the washed casing chips from any of the three runs met the cleanup goals (Table C-3).

C.2.4 Input and Output Flow Rate Stability

Figures C-6, C-9, and C-10 present the stream flows for the three Demonstration runs for feed soil, washed gravel, and sand. These data show that, at 2.4 to 4.2 tph, the BESCORP unit operated satisfactorily most of the time. From the data in Table C-6, process downtime was about 13 percent and nonprocess downtime was 8 percent for a total of 21 percent. Therefore, process on-line time was 87 percent. In Section 4, the economics for a commercial 20-tph BSWS unit are developed on the basis of 80 percent on-line time.

TABLE C-6. DOWNTIME SUMMARY FOR THE THREE RUNS

Cumulative total (3 runs)	Time* (min.)	Downtime (%)
Shutdowns Process Oriented		
Conveyor jam	91	
4 pluggings in chip separator	46	
Process **total**	137	13
Shutdowns Nonprocess Oriented		
Low make-up water flow	62	
City power failure	29	
Nonprocess total	**91**	**8**
OVERALL DOWNTIME	**228**	21

*Total run time 18 hours

C.3 REFERENCES

1. Guide to *Conducting Treatability Studies Under CERCLA: Soil Washing interim Guidance* EPA/540/2-91/020A. September 1992.

Appendix D
Case Studies: Full-scale Demonstrations and Treatability Studies [Provided by Vendor]

Using various process approaches, BESCORP performed full-scale demonstrations and treatability studies to determlne contaminant removal efficiencies. The studies focused on contaminant removal from soils of varying characteristics. The most important aspect regarding soil washing is an in-depth analysis of the contaminated soil through treatability studies and pilot-scale feasibility demonstrations. No soil-contaminant combination will establish a generic treatment process; a specific soil characteristic warrants a site-specific process approach. As illustrated at ABE, representative sampling is mandatory; a sampling plan that does not characterize the site adequately may prescribe a treatment process for site conditions that do not exist.

- Lead Site Remediations

  BESCORP tested material from five different lead-contaminated sites. Analytical results established a need for different process approaches for each site. BESCORP analyzed soils contaminated with lead in various forms: discrete metallics, battery casings, vegetation matrix, iron hydroxide precipitate, and mixed metals at an ammunition destruction site.

- Radium-Contaminated Soils

  BESCORP conducted an on-site treatability demonstration Involving Radium-226 contaminated soil, in which 50 percent of the material was minus 400 mesh. The field data demonstrated a qualitative ability to partition radium to 20 percent of the soil,

- Depleted Uranium-Contaminated Soils

  BESCORP conducted treatability testing for the removal of uranium metal and oxides from soil at a munitions testing site. The treatability testing targeted a combination of density separation and chemical leaching.

- Hydrocarbon-Contaminated Soils

  BESCORP demonstrated cleaning hydrocarbon-contaminated solls with and without surfactants. Results demonstrated the use of hlgh pressure and warm water as a stand-alone volume reduction process, or as a pretreatment for separating and feeding the contaminated fines to a bioslurry reactor.

CASE D.1 TREATABILITY STUDY AND SITE REMEDIATION: ARMY AMMUNITION PLANT

Location:	New Brighton, Minnesota
Plant Size:	20-tph mobile plant
Quantity:	1,900 tons (to be continued in summer 1994)
Process:	Water-based, physical separation system, using a coagulant only

Overview

Soil at a munitions manufacturing and testing she was expected to contain only process residue, with contamination by lead stypphnate and other forms associated with initiators. A company, contracted to provide a leach process, discovered metallic lead in the soil, which would extend the leach time for processing the material to a prohibitive length. BESCORP was contracted to confirm the presence of metallic lead and establish a process for removal.

Bench-Scale Study

The material was slzed and treated to obtain a dense material fraction and a clean fraction. Size distribution of the material is presented In Table D-1.

The soil was contaminated with discrete, metallic-lead particles from plus 8 mesh to mlnus 200 mesh.

TABLE D-1. PARTICLE SIZE AND LEAD DISTRIBUTION AT AN ARMY AMMUNITION SITE

Size	%	Pb, ppm
+ ¼ inch	11.3	0
-¼inch to +8 mesh	4.7	0
-8 to -30 mesh	12.1	1,436
~30 10 + 50 mesh	25.4	1,025
-50 to+100 mesh	20.9	901
~100 to + 140 mesh	4.6	948
-140to +200 mesh	1.4	940
~200 mesh	19.6	679
TOTAL-	100.0	

Duplicate process runs resulted in removal efficiencies from 43 to 91 percent, with final lead concentrations ranging from 139 to 739 ppm Pb. The minus 200 mesh fraction was the most contaminated. This high concentration of lead is quite amenable to leaching. Subsequent leaching tests were conducted on composite material of all mesh sizes, where removal of 80 to 90 percent of the remaining lead was accomplished. This easily met the anticipated 300 ppm Pb discharge limit.

Full-Scale Application

At the Twin Cities Army Ammunition Plant (TCAAP), located in New Brighton, Minnesota, BESCORP is providing excavation and soil-washing services for soils contaminated with eight metals. BESCORP's process, coupled with the COGNIS TerraMet leaching system, is performing complete soil remediation. Lead extracted from the processed soil is being recovered and shipped to a smelter for reuse. All processed soil is being returned to the site.

Site "F," located wtihin the four-square-mile TCAAP site, was originally a munitions burning and burial area. The site is part of the Army's $370 million Installation Restoration Program. Remediation Is being conducted under a Resource Conservation and Recovery Act permit. Remedial investigations determined that lead levels in trenches and shallow soils over the three-acre area exceeded 4,000 ppm. While lead was identified as the primary metal of concern, seven other sites were discovered at high levels throughout Site F. Ash, residues, metallic lead, and copper spread over the site. In addition, 0.30 and 0.50 caliber casings and cyanlde pots were buried in trenches throughout the plant.

Remedial alternatives, such as solidification/stabilization and land filling, were evaluated and dismissed because these techniques leave the metals in the soil and continue the risk for long-term liability. The involved parties determined to evaluate soil-washing as the long-term solution.

Soil-Washing Activities

In the spring of 1993, COGNIS and BESCORP conducted joint treatabiltty and bench-scale studies in order to determine the applicablllty of their processes to complete soil remediation. The studies determined the following:

- BESCORP's Soil Washing System could be linked with the COGNIS TerraMet™ process to treat the separated fines as a continuous and complete soil treatment process.

- Site "F" soils could be successfully treated to meet the required cleanup levels specified below in Table D-2.

BESCORP commenced construction of a high-throughput plant designed around the process demonstrated at the ABE Superfund Site under the EPA

TABLE D-2. CLEANUP LEVELS FOR TCAAP

Metal:	Sb	Cd	Cr	Cu	Pb	Hg	Ni	Ag
Performance goal (mg/kg):	4	4	100	80	300	0.3	45	5

SITE Program In 1992. The new plant was completed In July 1993. In the fall of 1993, 2,000 yds of material were processed and the material stockpiled on-site until the remainder of the material could be processed and the cleaned soils graded back onto the site. The time (shipping the unit, on-site set-up, and shakedown) totalled 17 days.

The five-trailer, full soil treatment process (BSWS and COGNIS) was situated at Site "D," a 185 ft x 100 ft cement pad equipped with sumps and bins for holding processing soil. The pad, originally built for a PCB-treatment process, was an ideal location for processing as it was located only 1,500ft from the excavation area.

Process Performance

The full-scale, soil washing and leaching system acceptance period started on September 17, 1993 with 340 tons of excavated and stockpiled material. The cleanup goals were met, and material processed until temperatures dropped to freezing and activity had to be interrupted until the spring of 1994.

It is believed that Site "F" contains approximately 7,500 tons (5,000 yds) of metal-contaminated soil. To date, approximately 1,900 tons have been successfully remediated; clean, processed soil has been transported from the soil-washing area back to Site "F" for redepositing and seeding with native vegetation.

CASE D.2 REMOVAL OF MINUS 100 MICRON (150 MESH) MATERIAL: HANFORD SIMULATED SOIL

Location:	Prosser, Washington
Plant Size:	20-tph mobile plant
Quantity:	500 yards (900 tons) processed
Process:	Water-based, physical separation system. using a coagulant only

Overview

Analysis, by Westinghouse Hanford Company, of Hanford soils contaminated with heavy metals (including Uranium 238, 235, cobalt, and cesium) determined that contaminants can be partitioned to the minus 100 micron (-150 mesh) soil fraction. In 1991, BESCORP conducted laboratory tests for determining the applicability of using a water-based physical process for removing minus 100 micron soil particles from Hanford-type (gravely-sandy) soils. Based on those results, BESCORP constructed a 20-tph plant in Prosser, Washington, for testing and demonstration purposes.

Using the 20-tph plant, BESCORP achieved verification of the particle size cut by washing 900 tons of noncontaminated Hanford simulated soil.

Documented Evidence (Process Approach and Efficiency)

Informal demonstrations were conducted for Ebasco Environmental, Westinghouse, and Battelle personnel wtih the 20-tph plant In Prosser, Washington. Based on these demonstrations and an evaluation of the system's efficiency using water In conjunction with a coagulant, the BESCORP System was included in a presentation by R.L. Treat at Environmental Restoration (ER) '91.

Efficiency data (below) were included in the presentation at ER '91 regarding the ability of the system to produce an excellent separation of coarse and fine soil. While the plant was processing material at 20 tph, Intermountain Materials Testing, Inc. collected samples and performed the analysis in accordance with ASTM C136, D422, and D1140, respectively.

The results highlight the ablilty of the BSWS to separate the fine soil fraction, using a water-based process. Essentially no fines in the coarse fraction were leaving the plant, and no coarse material was associated with the separated fines (Table D-3).

TABLE D-3. SIZE SEPARATION EFFICIENCY

Sieve size (mesh)	Stream 1 (coarse discharge) % passing	Stream 2 (fine discharge) % passing
4 in.	100	100
10	95	100
20	64	100
40 (0.42 mm)	33	100
80 (0.177 mm)	1	100
200 (0.074 mm)	0.3	99
270 (0.053 mm)	0	97
400 (0.037 mm)	0	84
635 (<0.037 mm)	0	62

CASE D.3 DISCRETE PARTIAL RECOVERY PLANT: TRAMWAY BAR MINE, ALASKA

Location: Tramway Bar, Alaska
Plant Size: 150 tph
Quantity: 71,400 tons processed
Process: Water-based, physical separation system, using a coagulant only

Overview

A 150-tph plant was built In 1989, processing 42,000 yards (71,400 tons) of material. Designed originally for separating gdd fines, the process was adapted for use in the soil remediation arena. The system operated successfully, classifying material, and appealed to both miners and the regulatory agencies, because of its low water requirements and high classification efficiency. The 150-tph plant generated the results shown in Table D-4, where recovered clean material totalled 97.5 wt percent.

TABLE D-4. MATERIAL BALANCE FOR A 150-TPH PLANT

Material	TPH
Clean material	146.3
Soil fines (to waste container)	3.75
Secondary waste	0.56

$$\text{wt. percent recovered} = \frac{150\ 3.75 - 0.56}{150} \times 100 = 97.5\%$$

CASE D.4 ON-SITE FIELD TEST: RADIUM-CONTAMINATED SOIL AT OKLAHOMA AIR FORCE BASE

Overview

In conjunction with a teaming partner, BESCORP conducted on-site demonstrations at a site contaminated with radium as a result of manufacturing activities. The area was partially excavated, samples were collected, and the remaining material stored.

Demonstration Results

Soil samples were collected from storage drums and screened for activity with a NaI scintillation gamma detector. Two of the samples were sized and monitored for radiation. Relative Geiger counter rates were recorded as an indication of residual radium in each fraction. The test showed that activity was primarily confined to 20 percent of the soil.

The soil consists almost entirely of clay; however, radium was found to consist of medium-sized, dense particles. High attrition breakdown of the clay, along with a highly efficient gravity separation process, was determined to be an effective remedial approach.

CASE D.5 COPPER WIRE INCINERATION AND RECOVERY SITE TREATABILITY STUDY: LEAD-CONTAMINATED SOIL

Overview

A wire burning site was the location of a previous copper recycling effort. BESCORP's testing was performed as a joint treatability study with a teaming partner that has metal leaching and recovery processes. BESCORP provided an up-front physical process, removing 50 to 75 percent of the total lead and 50 percent of the Initial copper. The initial material contained 12,000 ppm Pb (1.2 percent) and 100,000 ppm copper (10 percent).

Bench-Scale Study

The initial screening tests consisted of material sizing to obtain a soil histogram and to determine the extent of lead contamination. The material contained obvious pieces of copper wire, and occasionally a chunk of melted and soldified solder. Treatability test results determined that remediation could be accomplished with a combination of soil sizing and gravity separation, with a chemical leach of the soil fines. Typical results on replicate samples for size distribution and resulting lead and copper concentrations are presented in Table D-5.

Removal efficiency with a mineral Jig (based on the percentage in the concentrate) was 86.8 percent for lead, and 77.7 percent for copper. Typical amounts of soft incorporated into the gravity concentrate were from 4.3 percent to 8.9 percent of the feed. This was achieved with a single pass. It is expected that the feed percentage in the concentrate will decrease with a full-scale process, which will incorporate a secondary concentration process.

TABLE D-5. PARTICLE SIZE AND METALS DISTRIBUTION AT A COPPER WIRE SITE

Particle mesh size	Feed soil wt. %	Pb (ppm)	Copper (ppm)
+40	15.8	2,500	31,600
-40 to +140	6.2	2,500	60,000
-140	48.9	3,330	33,000
Jig concentrate	NA	80,000	324,000
TOTAL	70.9		

CASE D.6 LEAD-CONTAMINATED METAL RECYCLING FACILITY

Overview

The site was previously used for automobile metal recovery and recycling, with deposition debris on-site. The contaminant of prlme concern is lead.

Bench-Scale Study

The soil consists of debris that one might imagine to be present at a site where complete cars were hydraulically smashed for compactlon prior to shipment for reprocessing: plastic bits and pieces, metel, bits of debris (wood chlps, paper, and cardboard), and a tremendous amount of iron hydroxide precipitate.

Lead contamlnatlon, as a function of particle size, Is depicted In Table D-6.

soil washing of the material wlth magnetic separation did not improve lead segregation. An attrition scrubber removed iron oxide from the surface of the material, and segregated the lead to the finer fractions. The treatment results are presented In Table D-7.

Preliminary results indicate decreased levels of lead contamination in the matertial. Further Improvement of the attrition process to remove lead from the coarse fractlons should improve the subsequent leach process and potentially reduce the fraction that must be leached. Current treatability tests indicate lead concentration after leaching to be In the range of 50 ppm.

TABLE D-6. PARTICLE SIZE AND LEAD DISTRIBUTION AT A LEAD RECYCLING FACILITY

Particle mesh size	%	Pb (ppm)
+4	35.5	4,000
-4 to +8	14.3	3,050
-8 to +40	18.4	3,450
-40 to +140	14.0	5,450
- 140	17.8	NA
TOTAL	I00.0	

TABLE D-7. PARTICLE SIZE AND LEAD DISTRIBUTION BEFORE AND AFTER TREATMENT

Particle size	Pb ppm (prior to attrition)	Pb ppm (after attrition)
+4 mesh	4,000	ND
-4 to +8 mesh	3,050	1,065
-8 to + 20 mesh	3,100	500
-20 to +40 mesh	3,450	1,980
-40 to +140 mesh	5,450	5,400

*ND- Nondetectable

CASE D.7 LEAD-CONTAMINATED TARGET RANGE SITES

Overview

The site (conisting of three areas) was used for skeet and small arms shooting; lead shot was distributed over a large field.

Bench-Scale Treatability

The soil was sized to obtain an initial split of the material for delineating lead distribution. Large quantities of lead shot were found at the site, and extremely large amounts of lead bullets were found in a small portion of the site. Shot was also found in samples from areas that were supposedly not used for skeet activity.

Table D-8 shows that analysis of organic material (grass, etc.) revealed lead concentrations exceeding 4 percent, which was surprising since this level of bioaccumulated lead had not been encountered at any other site. Work has yet to be performed to determine how the lead is bound in the vegetation.

With exception of the Site 3 material, the BESCORP process is expected to achieve 65 to 75 percent volume reduction, the remainder of the soil consisting of dense metallic material suitable for recycling. BESCORP is investigating the possibility of the vegetation being used for lead recovery by thermal destruction in a lead smelter. This would eliminate the need for off-site disposal.

TABLE D-8. PARTICLE SIZE AND LEAD DISTRIBUTION AT TARGET RANGES

Site 1

Particle mesh size	%	Pb, ppm
+4	4.8	---
-4 to +40	16.0	635
-40 to +140	67.6	545
-140	11.6	3,670
TOTAL	100.0	

Site 2

Particle mesh size	%	Pb, ppm
+4	6.3	1,500
-4 to +40	1.0	1,000,000
-40 to +140	79.1	25
-140	13.6	1,452
TOTAL	100.0	

Site 3

Particle mesh size	%	Pb, ppm
+4	14.7	1,000,000
-4 to +40	7.7	1,000,000
-40 to +140	67.0	7,387
-140	10.6	24,000
TOTAL	100.0	

CASE D.8 TREATABILITY STUDY: HYDROCARBON-CONTAMINATED SOILS

Overview

Treatability studies on hydrocarbon-contaminated soils were performed at military facilities in Alaska. The work focused on successfully cleaning the soil oversize and processing the hydrocarbon-contaminated fines with a bio-slurry reactor.

Bench-Scale Study

The bench-scale study of hydrocarbon removal from soils has consisted of determining the ability of the system to clean the plus 40 mesh material to a hydrocarbon contamination level that will allow for redeposit on-site (<l00 mg/kg total petroleum hydrocarbon). The minus 40 mesh soil will be treated by a bio-slurry reactor to destroy the hydrocarbons removed from the oversize. The entire process is accomplished either with a surfactant-augmented water wash or a steam wash.

Volatilization of the organic material and associated health hazards are potential problems with the steam wash. However, the contaminated samples consisted of residual diesel and jet fuel. BESCORP achieved a cleaner fraction wfth steam (96 and 108 ppm) than with a surfactant wash (270 ppm).

The studies to date have investigated the ability to treat residual hydrocarbons, which are the largest volume of contamination in our locale. BESCORP plans to expand the BSWS treatment capabilities to handle diesel-range and, eventually, gasoline-range hydrocarbons.

CASE D.9 URANIUM-CONTAMINATED SOILS

Overview

The site was used by an armament manufacturer for testing depleted uranium munitions. The contamination is limited to a catch box and surrounding area where vibration has spread the contamination. The uranium exists as discrete metallic pieces and uranium oxides, which are quite friable and can be segregated to the fine soil fractions.

Treatability Study

The treatability study is a joint effort using physical processing for the removal of discrete uranium in conjunction with chemical leaching of soil fines for removal of metallic and oxide uranium.

The sample was lnitially sized and uranium concentrations in each fraction were measured by gamma spectroscopy. The material did not show any significant distribution of uranium versus size. Gravity separation of the material within each size range produced a uranium concentrate of a consistent and appreciable fraction. Analysis revealed uranium concentrations as high as three percent in the sample. The results are proprietary. However, a combination of physical and chemical processes will remediate the soil to acceptable release criteria.

CASE D.10 ABE TREATABILITY STUDY

Overview

The ABE NPL ske was chosen for the BESCORP SITE Demonstration based on the Remedial Investigation (RI) that was performed in 1999. The RI stated that the lead was in the fine soil material on the site (i.e., no discrete metallic-lead, no battery casings, and no casing chips), which would have been a perfect match for the BSWS.

However, the material excavated for the SITE Demonstration was considerably different from this material. The stockpile of material excavated was approximately 10 to 15 percent battery casings with visible metallic portions of lead add batteries.

Treatability Tests on RI Sample

lnitffl BESCORP work was performed on a sample from the RI (Sample B-7). which was sized to determined the distribution of the material and the lead content of each fraction. The data for the minus 1/4 inch raw sample are shown in Table D-9.

TABLE D-9. PARTICLE SIZE AND LEAD DISTRIBUTION IN RI RAW SAMPLE

Particle mesh size	Soil wt.%	Pb, ppm
+8	7.58	190
-8 to +30	2.80	19,300
-30 to +50	7.79	1,190
-50 to +100	12.44	548
loo to +140	9.30	772
140 to +200	10.89	1.090
-200	40.83	1.820
TOTAL	IO0.00	

TABLE D-10. LEAD DISTRIBUTION IN RI SAMPLE AFTER PROCESSING

Material	%	Pb (ppm)
(s.g. 0.9-1.3) float (casing chips)	1.9	6,850
(s.g. 1.3-2.5) light	82.0	252
(s.g. 2.5-5.0) mid	14.6	862
(s.g. 5.0-10.0) heavy (lead)	1.5	9,117
TOTAL	100.0	

TABLE D-11. LEAD DISTRIBUTION IN SECOND FRACTION OF RI SAMPLE AFTER PROCESSING

Material	%	Pb (ppm)
(s.g. 0.9-1.3) float (casing chips)	2.1	3,975
(s.g. 1.3-2.5) light	87.6	354
(s.g. 2.5-5.0) mid	10.1	1,040
(s.g. 5.0-10.0) heavy (lead)	0.2	51,282
TOTAL	100.0	

When a portion of this materlal was processed by gravity and density separation. products contained the lead distribution indicated in Table D-IO. The specific gravity ranges are approximations, as the size of the particle and the density determine where the material will collect. Good results are expected for the gravity process at this site. A second size fraction, minus 50 to plus l00 mesh, was distributed as shown in Table D-11.

A second portion of the B-7 sample was processed on a mineral jig, and the concentrate measured 164,000 ppm Pb. The tails analysis was found to contain 848 ppm Pb. After the tails were washed to remove the -200 mesh matarial, the analysis was 261 ppm lead. The fines themselves were analyzed to 2,200 ppm Pb. This data further supports the gravity separation as a reasonable approach to process this material. The size separation is also shown to be important. With a total lead content of 261 ppm, the maximum TCLP lead value would be 13 ppm if 100 percent of the lead was dissolved.

BESCORP was proceeding with this evaluation when they were advised that they would need to remove the battery casings from the on-site material, as well as needing a circuit to remove the discrete, metallic-lead particles that were present in the excavated material.

With a short time frame to develop and implement both a dense and a light fraction circuit capable of operating over a size range of minus 2½ inch to plus 150 mesh, attention was focused on the processing rather than the further analysis.

Further sample work was performed on the excavated material to verify the process approach and the effectiveness on the "real" ABE Site soil.

Treatability Tests on Feed Pile for SITE Demonstration

The samples treated in the BESCORP plant simulation were taken randomly from the surface and subsurface of the excavated stockpile. Typical results from the simulated process are listed In Table D-12.

In retrospect, these data show how important the cut point for the size classification is, but BESCORP did not anticipate prior to the SITE Demonstration that the small portion of minus 100 to plus 140 mesh material (two percent of the sand screw discharge) would have such a high lead content and that it would exert the subsequent adverse effect on the product (sand) stream analysis. This lead content exceeded the redeposit limits for the washed sand fraction. Post-SITE Program treatability tests, presented In Appendix B, show the preferred cut point for the sand fraction to be about plus 80 mesh.

TABLE D-12. PARTICLE SIZE AND LEAD DISTRIBUTION IN RI SAMPLE AFTER SIMULATED PROCESSING

Particle mesh size	Pb (ppm)
-8 + 100 mesh	256
-100 + 140 mesh	2,540
-140 + 200 mesh	1,600
-200 mesh	8,420