

**Resources Conservation Company
B.E.S.T.® Solvent Extraction Technology**

Applications Analysis Report

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



Printed on Recycled Paper

Notice

The information in this document has been funded by the U.S. Environmental Protection Agency (EPA) under the auspices of the Superfund Innovative Technology Evaluation (SITE) Program under Contract No. 68-C0-0048 to Science Applications International Corporation (SAIC). It has been subjected to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use.

Foreword

The Superfund Innovative Technology Evaluation (SITE) Program was authorized in the 1986 Superfund Amendments. The SITE Program is a joint effort between the U.S. Environmental Protection Agency (EPA) Office of Research and Development and Office of Solid 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 technology demonstrations designed to provide engineering and economic data on selected technologies.

This project consists of an evaluation of the Resources Conservation Company (RCC) pilot-scale Basic Extractive Sludge Treatment (B.E.S.T.®) solvent extraction system. As a part of this evaluation, a demonstration test was conducted as a cooperative effort between U.S. EPA Region V, the Great Lakes National Program Office (GLNPO), the U.S. Army Corps of Engineers (COE), and the EPA SITE Program. The B.E.S.T.® Demonstration Test used Grand Calumet River sediment and took place at a centralized location immediately adjacent to the river in Gary, Indiana. The goals of the study, summarized in this Applications Analysis Report, are: 1) to assess the ability of RCC's pilot-scale B.E.S.T.® system to remove (extract) organic contaminants from the bottom sediments of the Grand Calumet River, using a patented solvent extraction technology that utilizes triethylamine as the solvent; 2) to evaluate the technology's potential beneficial effect on the metals found in the sediments, by changing the metallic compounds to less toxic or less leachable forms; 3) to assess the quality of the treated solids, water, and oil residuals; 4) to develop capital and operating costs for the technology; and 5) to provide an overall mass balance for organic contaminants (polynuclear aromatic hydrocarbons and polychlorinated biphenyls) around the B.E.S.T.® solvent extraction system. These goals were established by the SITE Program.

Additional copies of this report may be obtained at no charge from the EPA's Center for Environmental Research Information, 26 West Martin Luther King Drive, Cincinnati, Ohio, 45268, 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, (800) 553-6847. Reference copies will be available in the Hazardous Waste Collection at EPA libraries. Information regarding the availability of other reports can be obtained by calling the Office of Research and Development Publications at (513) 569-7562. To obtain further information regarding the SITE Program and other projects within SITE, telephone (513) 569-7696.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

Abstract

This document is an evaluation of the performance of the Resources Conservation Company (RCC) Basic Extractive Sludge Treatment (B.E.S.T.®) solvent extraction technology and its applicability as a treatment technique for soils, sediments, and sludges contaminated with organics. Both the technical and economic aspects of the technology are examined.

A demonstration of the RCC B.E.S.T.® solvent extraction system was conducted from July 1, 1992 to July 22, 1992 using RCC's pilot-scale unit to treat two composited sediments (Sediment A and Sediment B) collected from the Grand Calumet River. Operational data and sampling and analysis information were carefully compiled to establish a database against which other available data, as well as the vendor's claims for the technology, could be compared and evaluated. Conclusions were reached concerning the technology's suitability for use in removing organic contaminants from sediment.

The following conclusions are based on the demonstration test results collected by the Superfund Innovative Technology Evaluation (SITE) Program and supported by other available data, including demonstration test data collected by RCC:

- Contaminant concentration reductions of 96 percent for total polynuclear aromatic hydrocarbons (PAHs) and greater than 99 percent of total polychlorinated biphenyls (PCBs) were achieved for Sediment A. Contaminant concentration reductions of greater than 99 percent for total PAHs and greater than 99 percent for total PCBs were achieved for Sediment B.
- Removal efficiencies in excess of 98 percent were realized for both sediments for oil and grease.
- Mass balances conducted for total materials (including triethylamine) in the B.E.S.T.® system achieved closures of 99.3 percent and 99.6 percent for Sediment A and Sediment B, respectively. Mass balances comparing feed and product streams (excluding triethylamine) achieved closures of 108 percent and 114 percent for Sediment A and Sediment B, respectively.
- The products generated using the B.E.S.T.® process compared favorably with RCC's claims with regard to residual triethylamine concentrations. Treated solids produced during the optimum treatment runs for Sediment B had an average triethylamine concentration of 103 mg/kg. Water generated during these runs had a triethylamine concentration of 2.2 mg/L or less, while the oil product collected at the end of all Sediment B treatment runs had a triethylamine concentration of 733 mg/kg. Because very little oil product was generated during the treatment of Sediment A, the Sediment A oil product was not processed to reduce its triethylamine concentration. Solid product generated from the optimum treatment runs for Sediment A realized an average residual concentration of 45.1 mg/kg, while water products from the optimum treatment runs for Sediment A had triethylamine concentrations of 1.0 mg/L or less.
- The treatment cost for the remediation of contaminated soil, sediment, or sludge using the proposed 186-ton-per-day, full-scale B.E.S.T.® system is estimated at \$94 per ton if the system is on line 80 percent of the time or \$112 per ton if the system is on line 60 percent of the time.

Contents

<u>Section</u>	<u>Page</u>
Notice	ii
Foreword	iii
Abstract	iv
Contents	v
Tables	ix
Figures	x
Abbreviations	xi
Acknowledgments	xiii
 1. Executive Summary	 1
1.1 Introduction	1
1.2 Conclusions	1
1.3 Results	2
 2. Introduction	 3
2.1 The SITE Program	3
2.2 SITE Program Reports	3
2.3 Key Contacts	4
 3. Technology Applications Analysis	 5
3.1 Introduction	5
3.2 Conclusions	5
3.3 Technology Evaluation	6
3.4 Ranges of Site Characteristics Suitable for the Technology	8
3.4.1 Site Selection	8
3.4.2 Surface, Subsurface, and Clearance Requirements	8
3.4.3 Topographical Characteristics	9
3.4.4 Site Area Requirements	9
3.4.5 Climate Characteristics	9
3.4.6 Geological Characteristics	9
3.4.7 Utility Requirements	9
3.4.8 Size of Operation	9
3.5 Applicable Media	9
3.6 Regulatory Requirements	9
3.6.1 Federal Regulations	10
3.6.2 State and Local Regulations	13

Contents (Continued)

<u>Section</u>	<u>Page</u>
3.7 Personnel Issues	13
3.7.1 Training	13
3.7.2 Health and Safety	13
3.7.3 Emergency Response	14
3.8 References	14
4. Economic Analysis	15
4.1 Introduction	15
4.2 Conclusions	15
4.3 Issues and Assumptions	15
4.3.1 Costs Excluded from Estimate	15
4.3.2 Maximizing Treatment Rate	16
4.3.3 Utilities	16
4.3.4 Operating Times	16
4.3.5 Labor Requirements	16
4.3.6 Capital Costs	16
4.3.7 Equipment and Fixed Costs	16
4.4 Basis of Economic Analysis	16
4.4.1 Site Preparation Costs	17
4.4.2 Permitting and Regulatory Costs	17
4.4.3 Equipment Costs	17
4.4.4 Startup and Fixed Costs	18
4.4.5 Labor Costs	18
4.4.6 Supplies Costs	19
4.4.7 Consumables Costs	19
4.4.8 Effluent Treatment and Disposal Costs	19
4.4.9 Residuals and Waste Shipping, Handling, and Transport Costs	19
4.4.10 Analytical Costs	20
4.4.11 Facility Modification, Repair, and Replacement Costs	20
4.4.12 Site Demobilization Costs	20
4.5 Results of Economic Analysis	20
4.6 References	22
Appendix A - Process Description	23
A.1 Introduction	23
A.2 The B.E.S.T.® Pilot Unit	23

Contents (Continued)

<u>Section</u>	<u>Page</u>
A.3 Unit Operations	23
A.3.1 Feed Preparation	23
A.3.2 Extraction	23
A.3.3 Decantation, Solvent Recovery, and Oil Processing	25
A.3.4 Solids Drying	25
A.3.5 Water Stripping	26
A.3.6 Product Water Treatment	26
A.4 References	26
Appendix B - Vendor's Claims	27
B.1 B.E.S.T.® Process Effectively Removes PCBs and PAHs from Sediment	27
B.2 B.E.S.T.® Process Solvent Is Environmentally Friendly	28
B.2.1 Triethylamine Is Biodegradable	28
B.3 B.E.S.T.® Process Has No Air Emissions	28
B.4 SITE and RCC Analytical Results Closely Correlate	33
B.4.1 Overall Mass Balance Results	33
B.4.2 RCC QA/QC Requirements	33
B.5 B.E.S.T.® Process Performance Accurately Predicted by Bench-Scale Treatability Test Protocol	33
B.5.1 Bench-Scale Test vs. Pilot-Scale Test Data for Grand Calumet River Testing	33
B.5.2 Bench-Scale Test vs. Full-Scale Remediation	34
B.6 Other Pilot-Scale Test Project Results Substantiate SITE Demonstration Project Results	34
B.6.1 PCBs in Soils and Sediments at an Aluminum Manufacturing Site	34
B.6.2 PAHs in Sludge from Wood Treatment Facilities	34
B.6.3 PCBs in Soil at a Manufacturing Site	35
B.6.4 PAHs in Refinery Sludge	35
B.7 References	35
Appendix C - SITE Demonstration Results	36
C.1 Introduction	36
C.2 Contaminant Removal Efficiencies	36
C.3 Residual Triethylamine	37
C.4 Mass Balances	37
C.4.1 Solids Balance	38
C.4.2 PCB Balance	38
C.4.3 PAH Balance	38
C.4.4 O&G Balance	38
C.4.5 Water Balance	39

Contents (Continued)

<u>Section</u>	<u>Page</u>
C.4.6 Solvent (Triethylamine) Balance	39
C.4.7 Total Materials Balance	39
C.4.8 Feed and Product Materials Balance	39
C.5 Leaching Characteristics	39
C.6 PAH and PCB Concentrations in the Product Water and Product Oil	40
C.7 Air Emissions	40
C.8 Triethylamine Biodegradation Testing on Treated Solids	40
C.9 Particle Size Distribution	41
Appendix D - Case Studies	42
D.1 Massena, New York Pilot-Scale Testing	42
D.2 Pilot-Scale Testing of Wastes from Wood Treating Facilities	42
D.3 Pilot-Scale Testing of Waste from Machining Operations	43
D.4 Pilot-Scale Testing of Petroleum Refining Sludge	43
D.5 Full-Scale Treatment of Oily Sludges	43
D.6 Reference	43

Tables

<u>Number</u>		<u>Page</u>
1	Summary of Results from Optimum Runs (Three per Sediment)	2
2	Characterization of the Untreated Sediment (Averages from Three Optimum Runs)	6
3	Excavation Costs	17
4	Treatment Costs for 186-tpd B.E.S.T.® System Treating Contaminated Soil, Sediment, or Sludge	21
5	Treatment Costs as Percentages of Total Costs for 186-tpd B.E.S.T.® System Treating Contaminated Soil, Sediment, or Sludge	21
6	Projected Annual Downtime	22
B-1	SITE vs. RCC Analytical Results	33
B-2	SITE vs. RCC Analytical Results	33
B-3	Total Mass Balance Comparison	33
B-4	Transect 6 Testing Comparison	34
B-5	Transect 28 Testing Comparison	34
B-6	General Refining Site PCB Concentrations in Raw Sludge and Product Fractions	34
B-7	Aluminum Manufacturing Facility PCB Removal from Soils and Sediments	34
B-8	Wood Treatment Facilities PAH Removal from Sediments	35
C-1	Total PAH, Total PCB, and O&G Removal Efficiencies	37
C-2	Residual Triethylamine Concentrations	37
C-3	Mass Balance Summaries	38
C-4	Solids Mass Balances	38
C-5	PCB Mass Balances	38
C-6	PAH Mass Balances	38
C-7	O&G Mass Balances	39
C-8	Water Mass Balances	39
C-9	Triethylamine Mass Balances	39
C-10	Total Materials Mass Balances	39
C-11	Feed and Product Materials Mass Balances	39
C-12	PAH and PCB Concentrations in the Product Water	40
C-13	PAH and PCB Concentrations in the Sediment B Product Oil	40
C-14	Triethylamine Biodegradability in Treated Solids	41
C-15	Particle Size Analysis Results	41
D-1	Treatment of Aluminum Manufacturing Solids and Sludges	42

Figures

<u>Number</u>		<u>Page</u>
1	Sediment Collection Locations - East Branch of the Grand Calumet River	7
A-1	Generalized Diagram of the RCC B.E.S.T.® Solvent Extraction Process	24
B-1	Transect 28 PAH Summary	29
B-2	Transect 6 PAH Summary	30
B-3	Transect 28 PCB Summary	31
B-4	Transect 6 PCB Summary	32

Abbreviations

AAR	Applications Analysis Report	O&G	oil and grease
ARAR	Applicable or Relevant and Appropriate Requirement	ORD	Office of Research and Development
BDAT	Best Demonstrated Available Technology	OSHA	Occupational Safety and Health Administration
B.E.S.T.®	Basic Extractive Sludge Treatment	OSWER	Office of Solid Waste and Emergency Response
BOP	Basic Oxygen Process	PAH	polynuclear aromatic hydrocarbon
CAA	Clean Air Act	PCB	polychlorinated biphenyl
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act	PID	photoionization detector
COE	U.S. Army Corps of Engineers	POTW	publicly-owned treatment works
CPR	cardiopulmonary resuscitation	PPE	personal protective equipment
CWA	Clean Water Act	ppm	parts per million
EPA	Environmental Protection Agency	QA	quality assurance
GLNPO	Great Lakes National Program Office	QA/QC	quality assurance/quality control
gpm	gallons per minute	RCC	Resources Conservation Company
gpd	gallons per day	RCRA	Resource Conservation and Recovery Act
HEPA	high-efficiency particulate	RREL	Risk Reduction Engineering Laboratory
IDEM	Indiana Department of Environmental Management	SAIC	Science Applications International Corporation
MCL	Maximum Contaminant Level	SARA	Superfund Amendments and Reauthorization Act
NFPA	National Fire Prevention Association	SDWA	Safe Drinking Water Act
NPDES	National Pollutant Discharge Elimination System		

Abbreviations (Continued)

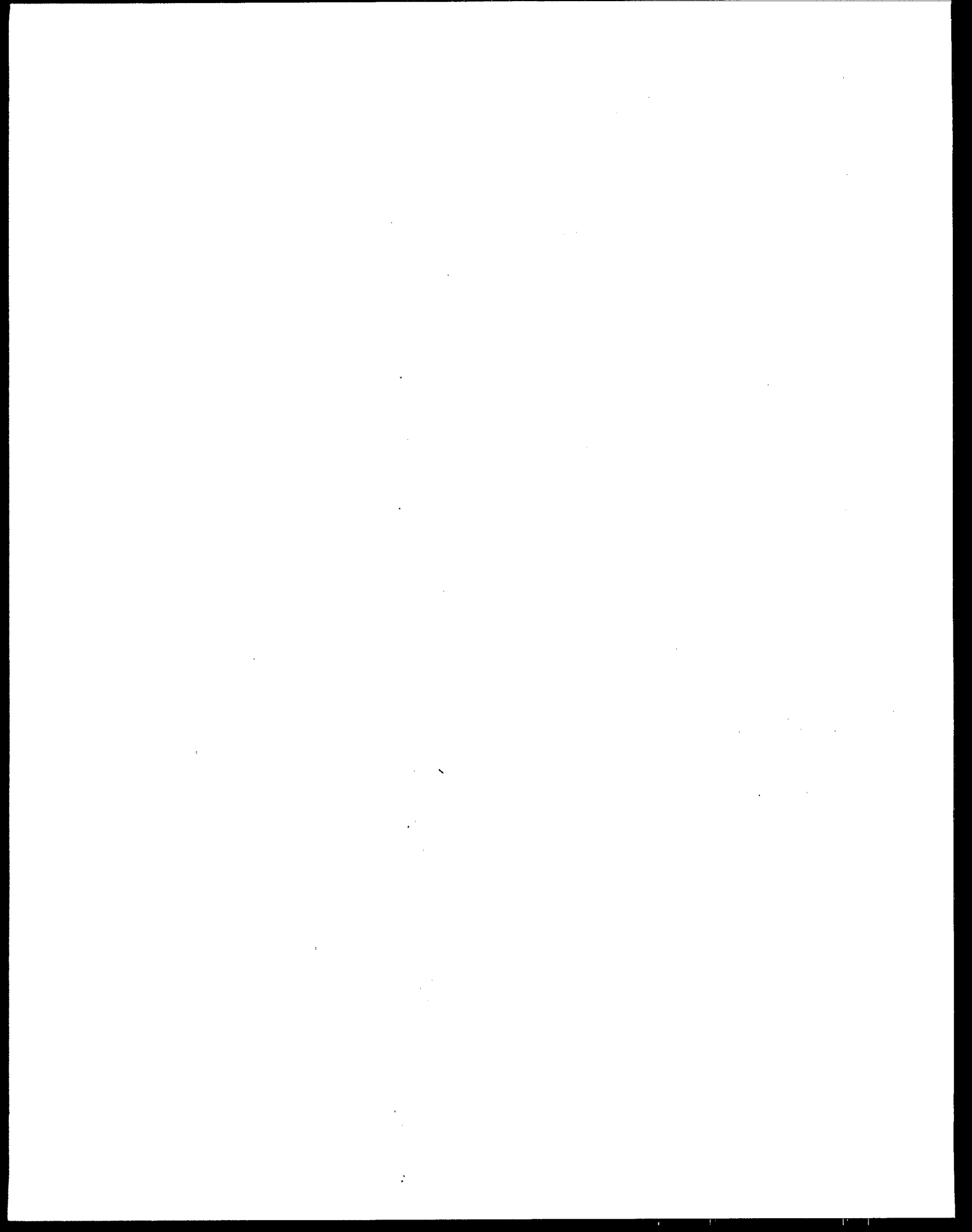
SITE	Superfund Innovative Technology Evaluation
TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total Dissolved Solids
TER	Technology Evaluation Report
tpd	tons per day
tph	tons per hour
TSCA	Toxic Substances Control Act
TSD	Treatment, Storage, and Disposal
TSS	Total Suspended Solids

Acknowledgments

This report was prepared under the direction and coordination of Mr. Mark C. Meckes, Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Project Manager in the Risk Reduction Engineering Laboratory (RREL), Cincinnati, Ohio. EPA-RREL contributors and reviewers for this report were Mr. Dennis Timberlake and Ms. Michelle Simon. Other contributors and reviewers were Mr. George Jones and Mr. Lanny Weimer of Resources Conservation Company; Mr. Stephen Garbaciak, Jr. of the EPA Great Lakes National Program Office; and Mr. Jay A. Semmler and Ms. Linda Diez of the U.S. Army Corps of Engineers.

This report was prepared for EPA's SITE Program by the Technology Evaluation Division of Science Applications International Corporation (SAIC) in Cincinnati, Ohio for the U.S. EPA under Contract No. 68-C0-0048. This report was written by Ms. Sharon Krietemeyer, Ms. Deana Demichelis, and Ms. Evelyn Meagher-Hartzell. The Work Assignment Manager for the project was Mr. Thomas Wagner.

Cover Photos: clockwise from top left are 1) bench-scale testing apparatus, 2) B.E.S.T.® pilot-scale unit, 3) collection of sediments from Grand Calumet River, 4) untreated sediments being homogenized, and 5) sediment feed being weighed prior to pilot-scale testing.



Section 1

Executive Summary

1.1 Introduction

This report summarizes the findings of an evaluation of the Basic Extractive Sludge Treatment (B.E.S.T.®) solvent extraction technology developed by Resources Conservation Company (RCC). As a part of this evaluation, a demonstration test was conducted as a cooperative effort between the U.S. Environmental Protection Agency (EPA) Region V, the Great Lakes National Program Office (GLNPO), the Army Corps of Engineers (COE), and the EPA Superfund Innovative Technology Evaluation (SITE) Program. During this demonstration test, the B.E.S.T.® system was used to treat composited sediments from two areas of the Grand Calumet River. Sediment collected from Transect 28 was screened and homogenized to form Sediment A, while sediment collected from Transect 6 was screened and homogenized to form Sediment B. The results of the demonstration test and supporting data from other testing performed by RCC constitute the basis for this report.

1.2 Conclusions

A number of conclusions may be drawn from the evaluation of this innovative technology. The most extensive data were obtained during the SITE demonstration test. The analytical results obtained by the SITE Program were substantiated by separate analytical results obtained by RCC. Data from other testing activities have also been evaluated in relation to SITE Program objectives. The conclusions drawn are:

- Contaminant concentration reductions of 96 percent for total polynuclear aromatic hydrocarbons (PAHs) and greater than 99 percent for total polychlor-

inated biphenyls (PCBs) were achieved for Sediment A. Contaminant concentration reductions of greater than 99 percent for total PAHs and greater than 99 percent for total PCBs were achieved for Sediment B.

- Removal efficiencies in excess of 98 percent were realized for both sediments for oil and grease (O&G).
- Mass balances conducted for total materials (including triethylamine) in the B.E.S.T.® system achieved closures of 99.3 percent and 99.6 percent for Sediment A and Sediment B, respectively. Mass balances comparing feed and product streams (excluding triethylamine) achieved closures of 108 percent and 114 percent for Sediment A and Sediment B, respectively.
- The products generated using the B.E.S.T.® process compared favorably with RCC's claims with regard to residual triethylamine concentrations. Treated solids produced during the optimum treatment runs for Sediment B had an average triethylamine concentration of 103 mg/kg. Water generated during these runs had a triethylamine concentration of 2.2 mg/L or less, while the composite oil product collected at the end of all Sediment B treatment runs had a triethylamine concentration of 733 mg/kg. Because very little oil product was generated during the treatment of Sediment A, the Sediment A oil product was not processed to reduce its triethylamine concentration. Solid product generated from the optimum treatment runs for Sediment A realized an average residual concentration of 45.1 mg/kg, while water products from the optimum treatment runs for Sediment A had triethylamine concentrations of 1.0 mg/L or less.

- The treatment cost for the remediation of contaminated soil, sediment, or sludge using the proposed 186-ton-per-day (tpd), full-scale B.E.S.T.® system is estimated at \$94 per ton if the system is on line 80 percent of the time or \$112 per ton if the system is on line 60 percent of the time.

1.3 Results

The objectives of this Applications Analysis are to assess the ability of the process to comply with Applicable or Relevant and Appropriate Requirements (ARARs) and to estimate the cost of using this technology to remediate a Superfund site. This analysis includes determining if the B.E.S.T.® process can 1) remove

organic contaminants from the bottom sediments of the Grand Calumet River; 2) exert a beneficial effect on the metals found in the sediments by changing the metallic compounds to less toxic or less leachable forms; 3) concentrate the organic contaminants into an oil phase; 4) produce a water phase that is relatively free of organic contaminants; and 5) provide an overall mass balance for organic contaminants (PAHs and PCBs) around the B.E.S.T.® solvent extraction system.

The treated solids and the untreated sediment both passed the Toxicity Characteristic Leaching Procedure (TCLP) test for metals, so it was not possible to draw any significant conclusions regarding the effects of the B.E.S.T.® process on metals leachability. The other results are summarized in Table 1.

Table 1. Summary of Results from Optimum Runs (Three per Sediment)

Parameter	Sediment A			Sediment B		
	PCBs	PAHs	Triethylamine	PCBs	PAHs	Triethylamine
Average Concentration in Untreated Sediment, mg/kg	12.1	550	NA ^a	425	70,900	NA ^a
Average Concentration in Treated Solids, mg/kg	0.04	22	45.1	1.8	510	103
Average Removal from Sediment, percent	99.7	96.0	NA	99.6	99.3	NA
Average Concentration in Oil Product, mg/kg	NA ^b	NA ^b	NA ^b	2,030	390,000	733 ^c
Maximum Concentration in Water Product, mg/L	<0.003	<0.01	1.0	<0.001	<0.01	2.2

Notes:

- a NA = not applicable. These samples were not analyzed for triethylamine.
- b The Sediment A oil product was sampled at the end of the last run conducted on Sediment A. When the oil was sampled, there was not sufficient oil present for oil processing to reduce the triethylamine concentration and as a result, excess triethylamine was left in the oil. The triethylamine concentration in the oil does not provide meaningful data regarding the typical characteristics of the oil product.
- c This oil product was sampled following normal oil processing, which reduces the triethylamine concentration.

Section 2

Introduction

2.1 *The SITE Program*

In 1986, the EPA Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) established the SITE Program to promote the development and use of innovative technologies to clean up Superfund sites across the country. Now in its sixth year, SITE is helping to provide the treatment technologies necessary to implement new Federal and state cleanup standards aimed at permanent remedies rather than quick fixes. The SITE Program is composed of four major elements: the Demonstration Program, the Emerging Technologies Program, the Measurement and Monitoring Technologies Program, and the Technology Transfer Program.

The major focus has been on the Demonstration Program, which is designed to provide engineering and cost data for selected technologies. To date, the Demonstration Program projects have not involved funding for technology developers. EPA and developers participating in the program share the cost of the demonstration. Developers are responsible for demonstrating their innovative systems at chosen sites, usually Superfund sites. EPA is responsible for sampling, analyzing, and evaluating all test results. The result is an assessment of the technology's performance, reliability, and costs. This information is used in conjunction with other data to select the most appropriate technologies for the cleanup of Superfund sites.

Developers of innovative technologies apply to the Demonstration Program by responding to EPA's annual solicitation. EPA also accepts proposals any time a developer has a Superfund waste treatment project scheduled. To qualify for the program, a new technology must be available as a pilot- or full-scale system and offer some advantage over existing technologies. Mobile technologies are of particular interest to EPA.

Once EPA has accepted a proposal, EPA and the developer work with the EPA regional offices and state agencies to identify a site containing waste suitable for testing the capabilities of the technology. EPA prepares a detailed sampling and analysis plan designed to evaluate the technology thoroughly and to ensure that the resulting data are reliable. The duration of a demonstration varies from a few days to several months, depending on the length of time and quantity of waste needed to assess the technology. After the completion of a technology demonstration, EPA prepares two reports, which are explained in more detail in Subsection 2.2. Ultimately, the Demonstration Program leads to an analysis of the technology's overall applicability to Superfund problems.

The second principal element of the SITE Program is the Emerging Technologies Program, which fosters the further investigation and development of treatment technologies that are still at the laboratory scale. Successful validation of these technologies can lead to the development of a system ready for field demonstration and participation in the Demonstration Program.

The third component of the SITE Program, the Measurement and Monitoring Technologies Program, provides assistance in the development and demonstration of innovative technologies to characterize Superfund sites better.

The fourth component of the SITE Program is the Technology Transfer Program, which reports and distributes the results of both Demonstration Program studies and Emerging Technology studies through the Technology Evaluation Reports (TERs), the Applications Analysis Reports (AARs), and abbreviated bulletins from both programs.

2.2 SITE Program Reports

The analysis of technologies participating in the Demonstration Program is contained in two documents: the TER and the AAR. The TER contains a comprehensive description of the demonstration sponsored by the SITE Program and its results. It gives detailed descriptions of the technology, the waste used for the demonstration, sampling and analyses during the test, the data generated, and the Quality Assurance (QA) program.

The scope of the AAR is broader than that of the TER. The AAR includes a description of projected Superfund applications and estimated costs for the technology. This report compiles and summarizes the results of the SITE demonstration, the vendor's design and test data, and other laboratory and field applications of the technology. It discusses the advantages, disadvantages, and limitations of the technology.

Costs of the technology for different applications are estimated based on available data from pilot- and full-scale applications. The AAR discusses the factors, such as site and waste characteristics, that have a major impact on costs and performance.

The amount of available data 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 full-scale level. In addition, there are limits to conclusions regarding Superfund applications 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 synthesize whatever information is available and draw reasonable conclusions. This document is very useful to those considering a technology for Superfund cleanups and represents a critical step in the development and commercialization of the treatment technology.

2.3 Key Contacts

For more information on the demonstration of the RCC B.E.S.T.® technology, please contact:

1. EPA Project Manager for the SITE demonstration test:

Mr. Mark C. Meckes
U.S. Environmental Protection Agency
Risk Reduction Engineering Laboratory
26 West Martin Luther King Drive
Cincinnati, Ohio 45268
(513) 569-7348

2. Process vendor:

Mr. Lanny Weimer
Resources Conservation Company
3630 Cornus Lane
Ellicott City, Maryland 21043
(301) 596-6066

Mr. George Jones
Resources Conservation Company
3006 Northrup Way
Bellevue, Washington 98004-1407
(206) 828-2400

3. GLNPO Remedial Programs staff:

Mr. Stephen Garbaciak, Jr.
U.S. Environmental Protection Agency
Great Lakes National Program Office
77 West Jackson Boulevard
Chicago, Illinois 60604-3590

Section 3

Technology Applications Analysis

3.1 Introduction

This section addresses the applicability of the RCC B.E.S.T.® technology to contaminated soils, sludges, or sediments for which PCBs and PAHs are the pollutants of primary interest. Recommendations are based on the results obtained from the SITE demonstration as well as additional data from RCC. The results of the demonstration, which allow an evaluation of the effectiveness of the technology in treating contaminated sediment from the Grand Calumet River, are presented in the body of this report. Additional information on the B.E.S.T.® technology, including a brief process description, vendor's claims, a summary of the demonstration results, and brief descriptions of previous case studies, is provided in Appendices A through D.

This demonstration was a cooperative effort between the EPA - Region V, GLNPO, the COE, and the SITE Program. GLNPO is responsible for undertaking a 5-year study and demonstration program for contaminated sediments known as the Assessment and Remediation of Contaminated Sediments Program. The Assessment and Remediation of Contaminated Sediments Program is operated through a Management Advisory Committee made up of the chairpersons of the technical work groups, and the technical work groups themselves. The Assessment and Remediation of Contaminated Sediments Program is also involved in evaluating remedial activities of other groups such as the Superfund Program and the COE to evaluate the effectiveness of those activities.

3.2 Conclusions

The RCC B.E.S.T.® solvent extraction technology physically separates organic contaminants from an inorganic matrix, thereby reducing the volume of wastes which require further treatment. The process consists of multiple extraction cycles followed by solvent recovery, oil polishing (removing virtually all of the

triethylamine from the oil product by evaporation), solids drying, and water stripping. This technology utilizes the solvent properties and variable miscibility of triethylamine in water to separate oil-contaminated soils, sediments, or sludges into their oil, water, and solids fractions. A more detailed process description is provided in Appendix A.

The majority of the organic contaminants initially present in the sludge, sediment, or soil are concentrated in the oil fraction. This fraction may require additional treatment (e.g., incineration) to destroy or immobilize these contaminants. Whether the water and solids fractions can be disposed of or discharged without additional treatment depends on the treatment efficiency of the B.E.S.T.® process and the presence of inorganic contaminants. The demonstration test was performed to demonstrate the ability of the B.E.S.T.® system to remove PAHs and PCBs from contaminated sediments in the Grand Calumet River. This test was conducted at a Gary, Indiana location adjacent to the river.

During the demonstration test, samples were collected and analyzed separately by the SITE Program and by RCC. The two sets of analytical results were in excellent agreement. A review of the demonstration test indicates the following results:

- Contaminant reductions of 96 percent for total PAHs and greater than 99 percent for total PCBs were achieved for Sediment A. Contaminant reductions of greater than 99 percent for total PAHs and greater than 99 percent for total PCBs were achieved for Sediment B.
- Removal efficiencies in excess of 98 percent were realized by both sediments for O&G.
- Mass balances conducted for total materials (including triethylamine) in the B.E.S.T.® system achieved closures of 99.3 percent and 99.6 percent for Sediment A and Sediment B, respectively. Mass

balances comparing feed and product streams (excluding triethylamine) achieved closures of 108 percent and 114 percent for Sediment A and Sediment B, respectively.

- The products generated using the B.E.S.T.® process compared favorably with RCC's claims in regards to residual triethylamine concentrations. Treated solids produced during the optimum treatment runs for Sediment B had an average triethylamine concentration of 103 mg/kg. Water generated during these runs had a triethylamine concentration of 2.2 mg/L or less, while the oil product collected at the end of all Sediment B treatment runs had a triethylamine concentration of 733 mg/kg. Because very little oil product was generated during the treatment of Sediment A, the Sediment A oil product was not processed to reduce its triethylamine concentration. Solid product generated from the optimum treatment runs for Sediment A realized an average residual concentration of 45.1 mg/kg, while water products from the optimum treatment runs for Sediment A had triethylamine concentrations of 1.0 mg/L or less.
- The treatment cost for the remediation of contaminated soil, sediment, or sludge using the proposed 186-tpd, full-scale B.E.S.T.® system is estimated at \$94 per ton if the system is on line 80 percent of the time or \$112 per ton if the system is on line 60 percent of the time.

The vendor's claims for the B.E.S.T.® process are presented in Appendix B and detailed results are presented in Appendix C.

3.3 Technology Evaluation

The objective of this SITE demonstration was to demonstrate the effectiveness of the B.E.S.T.® solvent extraction technology on two sediment samples having different contaminants and/or contrasting concentration levels of the same contaminants. The contaminants in the river sediments include metals, organic compounds such as PAHs and PCBs, and inorganics including cyanide.

The sediment collection points are shown in Figure 1. Sediments were collected from two locations (Transect 28 and Transect 6) along the Grand Calumet River using hollow aluminum tubes which were driven approximately 5 feet into the soft river bottom. The "cores" from the tubes were emptied into buckets and transported to the demonstration location. These sediment samples were obtained by the COE for the

demonstration. Sediment A was a screened, homogenized composite of sediment samples collected from Transect 28, which is downstream from an oil-skimmed settling lagoon. This lagoon received wastewater from primary bar plate mills and a basic oxygen process (BOP) shop. This location was chosen to acquire a sample having a decreased organic concentration and a relatively high metals concentration.

The high metals concentration of Sediment A was designed to provide an evaluation of the B.E.S.T.® system's ability to reduce the leachability of metals. Despite its high metals concentration, the untreated sediment passed the TCLP test for metals, so it was not possible to draw any significant conclusions regarding the effects of the B.E.S.T.® process on metals leachability. The metals concentrations in the treated solids were similar to those in the sediment, indicating that no significant amount of metals was removed by the B.E.S.T.® system.

Sediment B was a screened, homogenized composite of sediment samples collected from Transect 6. Transect 6 is located downstream of a coke plant and upstream of Transect 28. O&G were visually observed in the sediment collected during recent bottom sediment core sampling in the vicinity of Transect 6. Sediment B contained high levels of petroleum-based contaminants (i.e., O&G and PAHs) but low levels of metals. Analytical data characterizing Sediment A and Sediment B, according to the main parameters of interest for this demonstration test, are presented in Table 2. Concentrations in Table 2 are given on a dry weight basis for all parameters except moisture.

Table 2. Characterization of the Untreated Sediment
(Averages from Three Optimum Runs)

Parameter	Sediment A	Sediment B
Total PCBs, mg/kg	12.1	425
Total PAHs, mg/kg	550	70,900
O&G, mg/kg	6,900	127,000
Moisture, percent	41	64

To characterize the materials used in this demonstration further, particle size analyses were performed for the untreated sediment (by wet sieve testing) and the treated solids (by dry sieve testing). Particle size distributions were prepared to demonstrate the ability of the B.E.S.T.® system to treat materials containing large fractions of fine particles. Approximately 40 percent and 57 percent of the particles in Sediments A and B, respectively, had diameters of 75 to 425 μm . The particle size distributions also indicated that 28 percent

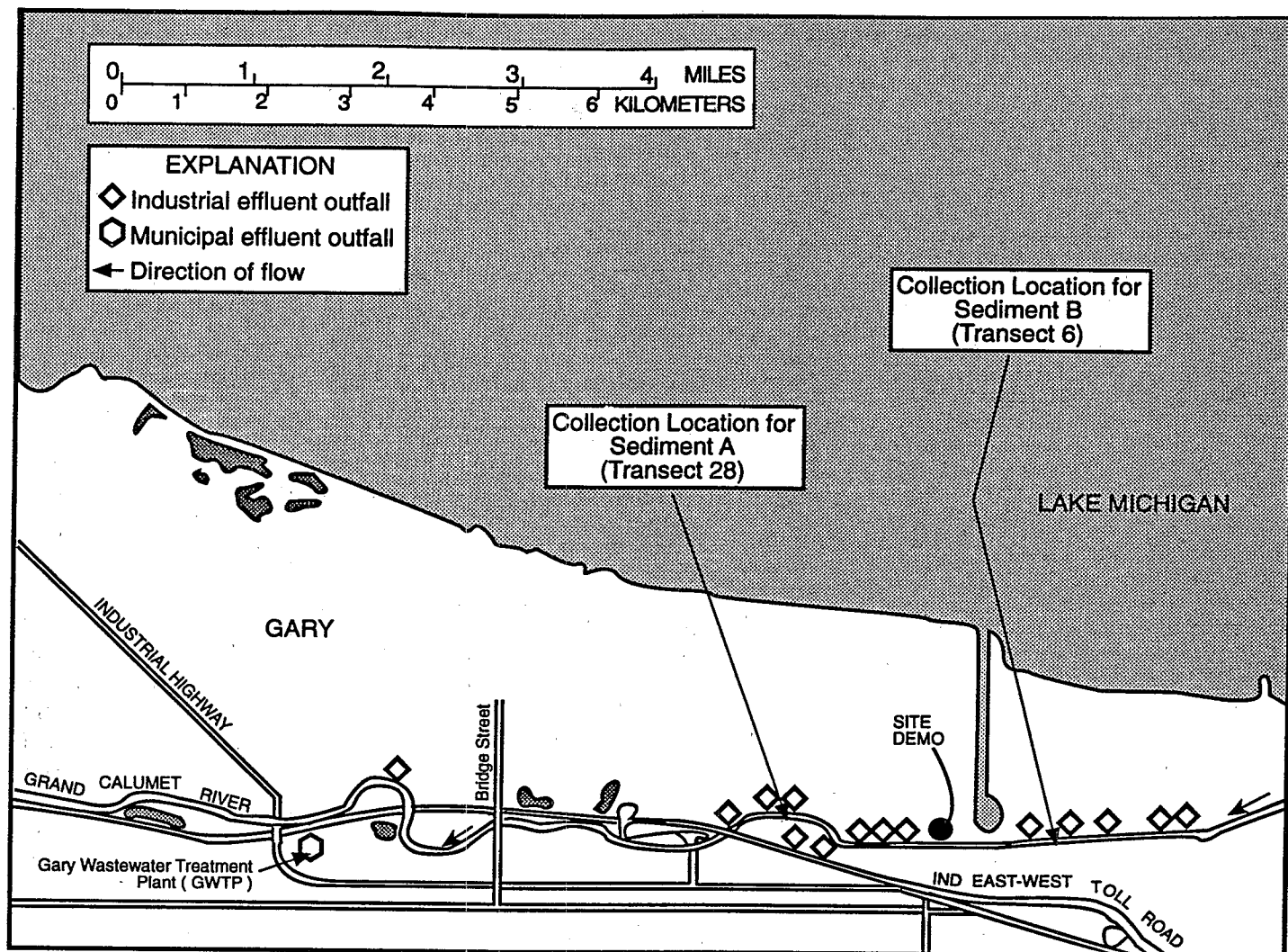


Figure 1. Sediment Collection Locations - East Branch of the Grand Calumet River.

and 38 percent of the particles in Sediments A and B, respectively, had diameters of less than 75 μm .

The demonstration site was located in Gary, Indiana near the Grand Calumet River. The Grand Calumet River drains approximately 77 square miles of Lake and Porter counties and discharges to southwestern Lake Michigan via the Indiana Harbor and Canal. Major industries along the waterway include primary steel and petrochemical industries. The river's headwaters are at the Grand Calumet River Lagoon at Marquette Park in northwest Gary. This "East Branch" of the Grand Calumet River flows westward through heavily industrialized sections of Gary and East Chicago. The Grand Calumet River is fed primarily by municipal and industrial wastewater (up to 90 percent of its flow) and a fairly rapid current is produced by these discharges

along several outfalls throughout the river's course. Flow is diverted due north via the Indiana Harbor and Canal, which discharges at East Chicago.

The Grand Calumet River/Indiana Harbor and Canal area has a long history of water quality problems and has been designated by EPA as an area of concern. The area of concern also includes nearshore Lake Michigan in Lake County, Indiana. Previous studies have been conducted by EPA Region V, the Indiana Department of Environmental Management (IDEM), and the COE. From these studies, the COE has estimated that the entire area of concern contains 3.5 to 4.0 million cubic yards of contaminated sediments and the East Branch of the Grand Calumet River contains 1.4 million cubic yards of contaminated sediments.

The majority of the RCC B.E.S.T.® pilot plant was constructed on two portable skids. One skid contained the B.E.S.T.® process equipment including the premix tank, extractor/dryer, centrifuge, centrate filters, oil decanter, stripping units, solvent evaporator, pumps, and valves required to process contaminated sludges or solids. Utility systems which supported the pilot plant were contained on a second skid. These systems included a refrigeration unit and a cooling water system. Steam, nitrogen, and instrument air were provided in separate units which were contained in a support trailer.

The process units utilized three levels of spill containment, the first being the pilot unit piping itself. Secondary containment consisted of a 2½-inch-deep stainless steel pan underlying the entire unit. Tertiary containment consisted of a flexible membrane liner with raised edges forming a berm. This liner was situated under the entire trailer unit in which the pilot plant was enclosed.

The B.E.S.T.® pilot-scale system is designed to process soil, sediment, or sludge feeds. The system separates organic contaminants from soils, sludges, and sediments, thereby potentially reducing the volume of the hazardous waste that must be treated. The technology uses amine solvents; triethylamine is most commonly chosen and was the solvent used during the SITE demonstration. Triethylamine is reported by RCC to be an excellent solvent for treating hazardous wastes because it exhibits several characteristics that enhance its use in a solvent extraction system. These characteristics include:

- A high vapor pressure; therefore the solvent can be easily recovered from the extract (oil, water, and solvent) via simple steam stripping.
- Formation of a low-boiling azeotrope with water; therefore the solvent can be recovered from the extract to very low residual levels, typically less than 100 parts per million (ppm).
- Triethylamine is alkaline (pH = 10); therefore some heavy metals are converted to metal hydroxides, which can precipitate and exit the process with the treated solids.

RCC's B.E.S.T.® pilot unit requires a feed stream that is screened to less than or equal to ½ inch, although the SITE demonstration utilized feed screened to less than or equal to ¼ inch to minimize abrasion to the equipment. The technology is capable of handling either "soil" type material or "sludge" type material, which determines the process path used in the pilot unit. RCC classifies material low in oil and water contents as "soil" and material having high oil and water content as "sludge." The sediment treated during the SITE

demonstration was considered a sludge by RCC. The vendor claims that the technology is suitable for treating inorganics contaminated with complex organic compounds including PAHs, PCBs, pesticides, and herbicides.

RCC has a full-scale unit that is capable of treating sludge but cannot handle soils. The proposed full-scale unit discussed in the following sections will be capable of treating either soil or sludge.

Limited testing to assess the biodegradability of triethylamine in the treated solids was conducted by the SITE evaluation team as part of the demonstration. Samples of the treated solids were mixed with clean soil that was intended as a source of naturally-occurring soil bacteria. This soil mixture was split into two cells and the biological activity in the control cell was inhibited by the addition of mercuric chloride. This biodegradation study produced no evidence that triethylamine present at 25 to 100 ppm is biodegraded in this soil within 2 months of application. This study should not, however, be considered evidence that triethylamine is not biodegradable in soil, since no attempt was made to optimize treatment parameters such as pH, nutrient availability, etc. The lack of biodegradation is supported by a previous study which used acclimated, activated sewage sludge [1]. In contrast, it has been reported that triethylamine is degraded in an *Aerobacter* bacterial culture [2]. These results indicate that residual triethylamine concentrations will not quickly biodegrade in this soil without the addition of nutrients and/or acclimated microbial strains.

The following paragraphs present information available on the B.E.S.T.® system and its performance and summarize observations and conclusions from the SITE demonstration.

3.4 Ranges of Site Characteristics Suitable for the Technology

3.4.1 Site Selection

The pilot-scale system used during the SITE demonstration is fully mobile and is contained on two skids. RCC states that the full-scale system will be transportable. It will be transported in sections and reassembled on or near the treatment site. The B.E.S.T.® system is applicable to sites containing soil, sediment, or sludge contaminated with organics. Any site on which the full-scale system is to be assembled should also meet the physical requirements described in the following subsections.

3.4.2 Surface, Subsurface, and Clearance Requirements

A level, graded area capable of supporting a pad holding the equipment is needed. The foundation must be able to support the weight of the B.E.S.T.® system and all other equipment requiring a pad. The dimensions of the pad or pads will depend on the configuration of the system. The total weight of the system and all auxiliary equipment is expected to be approximately 120 tons. The operating weight of the system, which includes the weight of the material being treated, is estimated to be 1,100 tons.

The site must be cleared to allow construction and access to the facility. It is estimated that the full-scale B.E.S.T.® system will be transported in 11 truckloads. The access road must be at least 8 feet wide to admit the trucks. The road should also be capable of supporting loads up to 40,000 pounds.

3.4.3 Topographical Characteristics

The topographical characteristics of the site should be suitable for the assembly of the B.E.S.T.® system. If no indoor storage is available at the site, a building must be constructed for spare parts storage.

3.4.4 Site Area Requirements

At least 1 acre should be available for the assembly of the B.E.S.T.® system. Once constructed, the system, storage tanks, and auxiliary equipment will occupy approximately 10,000 square feet (0.23 acres). For much of this area, a pad will be required to support the system. In addition, the National Fire Prevention Association (NFPA) requires that a perimeter be established around the solvent extraction equipment. This will increase the area required by the system. A separate area should also be provided for staging wastes for treatment and for storing treated solids. The required site dimensions will depend on the configuration of the full-scale system, which may be somewhat flexible.

3.4.5 Climate Characteristics

This treatment technology may be used in a broad range of climates, although prolonged periods of freezing temperatures may interfere with soil excavation and may require system modifications. Hot or cold climates may also impact energy costs for treatment, as specific liquid temperatures are required for the extractions.

3.4.6 Geological Characteristics

Generally, any site that is sufficiently stable to handle the weight of the system is suitable for this technology.

3.4.7 Utility Requirements

The only utilities required by the full-scale system are electricity and water. The site should have at least 430 kilowatts of 3-phase, 440-volt electrical power available. Potable water requirements are 1,020 gallons per day (gpd) for treatment, decontamination, etc. Steam and compressed air will be provided by a boiler and an air compressor that will be transported with the system.

3.4.8 Size of Operation

The pilot-scale B.E.S.T.® system was primarily contained on two skids and operated at an average treatment rate of approximately 90 pounds of contaminated sediment per day during the SITE demonstration. The proposed full-scale system will be much larger and will operate at a nominal processing rate of 186 tpd.

3.5 Applicable Media

The RCC B.E.S.T.® solvent extraction system is capable of physically separating organic contaminants such as PCBs, PAHs, and O&G from inorganic media. Media that can be treated by the pilot-scale system used during the SITE demonstration include soils, sediments, and sludges. The prototype full-scale system is only applicable to sludges, but the proposed full-scale system will be applicable to soils and sediments as well.

This technology has been demonstrated to be effective in removing organic contaminants from varied sources, including wastes generated by primary steel manufacturing, aluminum manufacturing, petroleum refining, machining operations, and wood treating. A summary of the pilot-scale testing projects appears in Appendix D.

The effectiveness of treatment is illustrated by the results of this demonstration project and by other case studies. This demonstration showed that the B.E.S.T.® process removed 96 percent of the PAHs, greater than 99 percent of the PCBs, and greater than 98 percent of the O&G from the contaminated sediments. Other process evaluations (discussed in Appendix D) documented PCB removals ranging from 98.8 percent to 99.88 percent, PAH removals ranging from 99 percent to 99.21 percent, and an O&G removal of 99.65 percent.

3.6 Regulatory Requirements

Operation of the B.E.S.T.® solvent extraction system for treatment of contaminated soil, sediment, or sludge requires compliance with certain Federal, state, and local regulatory standards and guidelines. Section 121 of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) requires that, subject to specified exceptions, remedial actions must be undertaken in compliance with ARARs, Federal laws, and more stringent promulgated state laws (in response to releases or threats of releases of hazardous substances, pollutants, or contaminants) as necessary to protect human health and the environment.

The ARARs which must be followed in treating contaminated media onsite are outlined in the Interim Guidance on Compliance with ARAR, Federal Register, Vol. 52, pp. 32496 et seq. These are:

- **Performance, Design, or Action-Specific Requirements.** One example is the Clean Water Act (CWA) pretreatment standards for discharge to publicly-owned treatment works (POTWs). These requirements are triggered by the particular remedial activity selected to clean a site.
- **Ambient/Chemical-Specific Requirements.** These set health-risk-based concentration limits based on pollutants and contaminants, e.g., emission limits and ambient air quality standards. The system must comply with the most stringent ARAR for each parameter.
- **Locational Requirements.** These set restrictions on activities because of site locations and environs.

Deployment of the B.E.S.T.® system will be affected by three main levels of regulation:

- Federal EPA air and water pollution regulations
- State air and water pollution regulations
- Local regulations, particularly Air Quality Management District requirements

These regulations govern the operation of all technologies. Other Federal, state, and local regulations are discussed in detail in the following paragraphs as they apply to the performance, emissions, and residues evaluated from measurements taken during the demonstration test.

3.6.1 Federal Regulations

3.6.1.1 Clean Air Act (CAA)

The CAA of 1990 regulates major sources of air toxics from specific source categories. The CAA revisions of 1990 included a statutory list of 189 substances which require regulation as air toxics. A draft list of source categories was also released in 1990. Triethylamine is one of the 189 listed air toxics and solvent extraction is on the draft list of source categories. The 1990 amendments define a "major source" as one which emits 10 tons per year of a single air toxic or 25 tons per year of any combination of air toxics. The triethylamine emission rate from the proposed full-scale B.E.S.T.® system has not yet been determined, but the process may be subject to regulation under the 1990 CAA revisions.

During the demonstration test, vent gases were filtered by primary and secondary activated carbon canisters. The air between the two carbon canisters was monitored daily with colorimetric tubes having detection limits of 3.5 ppm triethylamine. Triethylamine was detected at over 3.5 ppm in two instances during the demonstration. In each instance, the primary carbon canister was replaced immediately and the triethylamine concentration returned to below 3.5 ppm. The concentration of triethylamine at the vent gas outlet was not measured at over 0.2 ppm at any time during the demonstration.

3.6.1.2 Comprehensive Environmental Response, Compensation, and Liability Act

CERCLA of 1980, as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986, provides for Federal funding to respond to releases of hazardous substances to air, water, and land. Section 121 of SARA, Cleanup Standards, states a strong statutory preference for remedies that are highly reliable and provide long-term protection. It strongly recommends that remedial action use onsite treatment that "permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances." In addition, general factors which must be addressed by CERCLA remedial actions include:

- Overall protection of human health and the environment
- Compliance with ARARs

- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume
- Short-term effectiveness
- Implementability
- Cost
- State acceptance
- Community acceptance

The long-term effectiveness of the B.E.S.T.® system is demonstrated by its apparent ability to achieve a permanent and significant reduction in the volume of hazardous waste associated with soils, sediments, and sludges contaminated with organics. During treatment, the majority of the organic contaminants are extracted from the soil, sediment, or sludge and concentrated within the oily product. By removing the contaminants from the soil, sediment, or sludge and concentrating them within the oily fraction, the technology permanently isolates these contaminants from the treated solids, potentially enabling them to be backfilled onsite. In addition, a significant reduction in the volume of material requiring additional treatment and/or disposal is realized. Thus, a "permanent and significant" reduction in the threat posed by the waste is realized.

The B.E.S.T.® SITE demonstration was originally designed to evaluate reduction in metallic contaminant mobility. One of the goals of the demonstration was to evaluate the technology's potential ability to change metallic compounds to less toxic or less leachable forms. The treated solids and the untreated sediment both passed the TCLP test for metals, so it was not possible to draw any significant conclusions regarding the effects of the B.E.S.T.® process on the mobility of metallic contaminants.

Short-term effectiveness and overall protection of human health and the environment can be evaluated by examining the emissions from the B.E.S.T.® system. Solvent is recovered and recycled within the system, eliminating the need for waste solvent disposal. The water and oil products are decanted and processed (by solvent evaporation and water stripping) to minimize their solvent concentrations, to allow reuse of the triethylamine, and to reduce the likelihood that the water product will be classified as a hazardous waste. Since the process operates in a closed loop with one small vent for removal of non-condensable gases, air emissions are minimal. Air monitoring results from the SITE demonstration are discussed in Appendix C and subsection 3.6.1.1.

The B.E.S.T.® system appears to be capable of compliance with the known ARARs listed in Subsection 3.6. Locational requirements and local regulations are site-specific, and they must be evaluated individually for each site.

The B.E.S.T.® solvent extraction process is potentially capable of significantly reducing the toxicity of soils, sediments, and sludges contaminated with organics such as PAHs and PCBs. Depending on the other contaminants present and the treatment efficiency achieved, the treated solids may be suitable for onsite disposal without further treatment. During the demonstration test, the B.E.S.T.® solvent extraction technology removed greater than 96 percent and greater than 99 percent, respectively, of the PAHs and PCBs from the bottom sediment of the Grand Calumet River. If metals are present, the treated solids may require additional treatment such as fixation. The B.E.S.T.® system may be capable of changing the chemical nature of the metals into a less leachable form. However, since the untreated sediment passed the TCLP test for metals, this could not be assessed during the demonstration test.

The nature of the contaminants present also determines the disposal requirements for the water and oil products. In general, depending on the contaminants initially present and the effectiveness of the stripping steps employed, water products will often be suitable for discharge to a local POTW. Although the oil product may be suitable for use as a fuel, this product is more likely to require treatment or disposal as a hazardous waste. During the demonstration test, the elevated pH of the water product and PCB contamination within the oil fraction caused these materials to be designated as Resource Conservation and Recovery Act (RCRA) and Toxic Substances Control Act (TSCA) wastes, respectively. The elevated pH of the water product was due to the addition of excessive caustic during water stripping. The average pHs of the water products generated during the treatment of Sediments A and B were 12.3 and 11.9, respectively. RCC claims that the water product generated by the B.E.S.T.® system should not typically exhibit a pH greater than 11 after operators have become more familiar with the caustic addition requirements of a given feed stream. Depending on the B.E.S.T.® system configuration used and on the specific contaminants present in the feed material, an additional water treatment step may be needed during future applications of the technology to qualify the product water for discharge to a local POTW.

There are a number of basic site requirements for the B.E.S.T.® solvent extraction system. The system must not be operated in close proximity to combustible materials. Area requirements for staging of treated and untreated wastes will also make it difficult to implement this technology at sites with limited space. Furthermore,

the B.E.S.T.® full-scale system is rather complex and is not easily or quickly assembled or disassembled. As a result, the per ton remediation cost (including site preparation, system mobilization, startup, treatment, and demobilization) will be higher for small sites than for large sites. Unit costs for various treatment scenarios are provided in Section 4.

State acceptance and community acceptance are the last two factors that must be addressed by CERCLA remedial actions. It is not possible to predict whether a specific state or community will readily accept the B.E.S.T.® system, but potential community concerns include the flammability of the solvent, the obnoxious odor of the solvent, and potential explosion hazards.

3.6.1.3 Resource Conservation and Recovery Act

RCRA is the primary Federal legislation governing hazardous waste activities. Although a RCRA permit is not required for hazardous waste treatment on Superfund sites, the treatment systems must meet all of the substantive requirements of RCRA. Administrative RCRA requirements such as reporting and record-keeping, however, are not applicable for onsite activity.

Subtitle C of RCRA contains requirements for generation, transport, treatment, storage, and disposal of hazardous waste. Compliance with these requirements is mandatory for CERCLA sites producing hazardous waste onsite.

The water product generated during the demonstration test was a RCRA-regulated material due to its elevated pH. RCC states that the high pH of the water product was caused by excessive caustic added during water stripping. The water product generated by the B.E.S.T.® system should not typically exhibit a pH greater than 11. The nature of the water product will depend on the B.E.S.T.® system configuration used and the contaminants present in the waste. At many sites, however, the system should be capable of generating a water product amenable for discharge to the local POTW. In general, the production of hazardous residuals is dependent on the contaminants present within the untreated solids. Since the majority of the contamination collects within the oil product, this matrix is more likely than the water product to be regulated as a hazardous waste.

Since steam stripping and solvent evaporation are used to recover any residual triethylamine present in the water and oil separated from the extraction solution, solvent concentrations in system products are typically quite low. Average triethylamine concentrations of 103 mg/kg, <1 mg/L, and 730 mg/kg for solid, water, and oil products, respectively, were generated during the

treatment of Sediment B. Solid and water products generated from the treatment of Sediment A realized residual triethylamine concentrations of 45.1 mg/kg and 1.1 mg/L, respectively. Because this sediment contained very little oil, excess triethylamine could not be removed from the oil, and the triethylamine concentration in the Sediment A oil product is not considered representative of a typical product.

In order to maintain compliance with RCRA, sites employing the B.E.S.T.® system to treat hazardous wastes must obtain an EPA generator identification number and observe storage requirements stipulated under 40 CFR 262. Alternatively, a Part B Treatment, Storage, and Disposal (TSD) permit of interim status may be obtained. Invariably, a hazardous waste manifest must accompany offsite shipment of waste, and transport must comply with Federal Department of Transportation hazardous waste transportation regulations. Without exception, the receiving TSD facility must be permitted and in compliance with RCRA standards.

The technology or treatment standards applicable to the media produced by the B.E.S.T.® system (treated solids, product oil, and product water) will be determined by the characteristics of the waste treated and the material generated. The RCRA land disposal restrictions (40 CFR 268) preclude the land disposal of hazardous wastes which fail to meet the stipulated treatment standards. Wastes which do not meet these standards must receive additional treatment to bring the wastes into compliance with the standards prior to land disposal, unless a variance is granted. The following residuals were produced during the SITE demonstration: a water product classified as a RCRA waste due to elevated pH levels, an oil product that was a TSCA waste because it contained PCBs, and a potentially non-regulated solid product.

3.6.1.4 Clean Water Act

The CWA regulates direct discharges to surface water through the National Pollutant Discharge Elimination System (NPDES) regulations. These regulations require point-source discharges of wastewater to meet established water quality standards. The discharge of wastewater to a sanitary sewer requires a discharge permit or, at least, concurrence from state and local regulatory authorities that the wastewater is in compliance with regulatory limits.

The nature of the product, wash, and rinse water is site-specific; these matrices may be deemed hazardous waste at some sites. Although the product water generated during the SITE demonstration was not suitable for release to the local POTW due to elevated pH levels, this was simply due to addition of excessive caustic

during water stripping. It is projected that the system will typically generate a water product suitable for discharge to an industrial or municipal water treatment facility. Equipment rinse water from decontamination operations during the demonstration was suitable for discharge. In the commercial-scale system, the water product will be generated at a continuous flow rate of approximately 19 gallons per minute (gpm). Wash and rinse water production will be dependent on the frequency of decontamination as well as the extent of the contamination present.

3.6.1.5 Safe Drinking Water Act (SDWA)

The SDWA establishes primary and secondary national drinking water standards. CERCLA refers to these standards and Section 121(d)(2) explicitly mentions two of these standards for surface water or groundwater--Maximum Contaminant Levels (MCLs) and Federal Water Quality Criteria. Alternate Concentration Limits may be used when conditions of Section 121 (d)(2)(B) are met and cleanup to MCLs or other protective levels is not practicable. Included in these sections is guidance on how these requirements may be applied to Superfund remedial actions. The guidance, which is based on Federal requirements and policies, may be superseded by more stringent promulgated state requirements, resulting in the application of even stricter standards than those specified in Federal regulations.

3.6.1.6 Toxic Substances Control Act

Materials containing PCBs at concentrations of 50 ppm or greater are regulated by TSCA, which addresses disposal requirements in relation to the concentration of PCBs in the waste. The oil product generated during the demonstration test was a TSCA-regulated waste. Because organic contaminants from the feed are concentrated into the oil product, it is likely that the oil product will be a TSCA-regulated waste whenever significant quantities of PCBs are present in the feed. For example, consider Sediment A, which contained 12 ppm PCBs. The concentration of PCBs in the Sediment A oil product was approximately 190 ppm and would have been higher if more of the residual triethylamine had been removed from the oil. In cases such as this, the untreated material is not a TSCA-regulated waste but a TSCA-regulated oil product is generated during treatment.

3.6.2 State and Local Regulations

Compliance with ARARs may require meeting state standards that are more stringent than Federal standards or that are the controlling standards in the case of non-

CERCLA treatment activities. Several types of state and local regulations which may affect operation of the B.E.S.T.® system are cited below:

- Permitting requirements for construction/operation
- Limitations on emission levels
- Nuisance rules

3.7 Personnel Issues

3.7.1 Training

Personal protective equipment (PPE) levels for this demonstration were designated according to the potential hazards associated with each work activity. Equipment preparation, test start-up, and equipment decontamination activities were performed in Level D PPE. Level C PPE was required for sediment/chemical mixing and sample collection at the demonstration unit. All personnel are also required to be trained with 40 hours of Occupational Safety and Health Administration (OSHA) training covering PPE application, safety and health, emergency response procedures, and quality assurance/quality control (QA/QC). Additional training addressing the site activities, procedures, monitoring, and equipment associated with the technology is also necessary. Training provided prior to the operation of the system included information regarding emergency evacuation procedures; safety equipment locations; the boundaries of the exclusion zone, contaminant reduction zone, and support zone; and PPE requirements. These training procedures were observed throughout the demonstration.

3.7.2 Health and Safety

Personnel should be instructed about potential hazards, such as the flammability and explosiveness of the solvent, associated with the operation of the B.E.S.T.® system. Health and safety training covering recommended safe work practices, standard emergency plans and procedures, potential hazards and provisions for exposure monitoring, and the use and care of PPE should be required. Onsite personnel should participate in a medical monitoring program. Health and safety monitoring and incident reports should be routinely filed, and records of occupational illnesses and injuries (OSHA Forms 102 and 200) should be maintained. Audits ensuring compliance with the health and safety plan should be carried out.

Proper PPE should be available and properly utilized by all onsite personnel. Different levels of personal protection will be required based on the potential hazard 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. During the demonstration test, concerns were raised pertaining to the possible exposure of workers via inhalation and/or direct contact with contaminants present in the untreated sediment (e.g., PAHs and PCBs) and process chemicals used in the B.E.S.T.® solvent extraction technology (e.g., triethylamine and sodium hydroxide). In response to these concerns, air purifying respirators equipped with organic vapor cartridges and high-efficiency particulate (HEPA) filters or dust covers were required for workers in the immediate proximity of the pilot unit and during chemical/feed mixing operations.

Although the inhalation of contaminated soil-dust particles was a concern, dust exposure was not expected to be a problem under normal weather conditions. As a result, continuous particulate monitoring was not performed during the demonstration test.

Air monitoring was performed to determine the potential for respiratory or dermal hazards. A photoionization detector (PID) was used to assess the presence of ionizable organic vapors in the ambient air. Particular emphasis was placed on ambient monitoring for volatile emissions attributed to the solvent employed by RCC. The maximum limit for organic vapor concentration in the ambient air was 10 ppm above background levels; none of the measurements taken during the demonstration test exceeded this limit.

The health and safety practices described above were observed throughout the demonstration.

3.7.3 Emergency Response

In the event of an accident, illness, explosion, hazardous situation at the site, or intentional acts of harm, assistance should be immediately sought from the local emergency response teams and first aid or decontamination should be employed where appropriate.

To ensure a timely response in the case of an emergency, workers should review the evacuation plan, firefighting procedures, cardiopulmonary resuscitation (CPR) techniques, and emergency decontamination procedures before operating the system. Fire extinguishers, spill cleanup kits, and evacuation vehicles should be onsite at all times. Other onsite safety equipment will include an air horn that can be used to alert personnel in the event of an emergency.

3.8 References

1. Chudoba, J., et al. Chem Prum 19, pp. 76-80. 1969. (As referenced in Handbook of Environmental Fate and Exposure Data, Volume 2-Solvents. P. Howard, Ed. Louis Publishers, Chelsea, MI, 1991.)
2. U.S. Environmental Protection Agency. Treatability Manual, Volume 1 (EPA 600/8-80-042).

Section 4

Economic Analysis

4.1 Introduction

The primary purpose of this economic analysis is to estimate costs (not including profits) for commercial treatment utilizing the B.E.S.T.® system. This analysis is based on the results of a SITE demonstration which utilized a pilot-scale B.E.S.T.® solvent extraction system. To a lesser extent, this analysis is also based on information from previous tests, including a full-scale test conducted at the General Refining site in Garden City, Georgia. These previous tests are described briefly in Appendix D. The pilot-scale unit utilized during the SITE demonstration operated at an average feed rate of approximately 90 pounds of contaminated sediment per day; it is projected that the commercial unit will be capable of treating up to 186 tons of contaminated soil, sediment, or sludge per day.

4.2 Conclusions

The commercial-scale B.E.S.T.® system proposed by RCC is designed to remediate soils, sediments, and sludges contaminated with PCBs, PAHs, and other organics. Treatment costs appear to be competitive with other available technologies. The treatment cost for the remediation of contaminated soil, sediment, or sludge using the 186-tpd B.E.S.T.® solvent extraction system is estimated at \$112 per ton if the system is on line 60 percent of the time or \$94 per ton if the system is on line 80 percent of the time.

4.3 Issues and Assumptions

RCC states that the 186-tpd B.E.S.T.® system is applicable for sites having greater than 5,000 cubic yards (approximately 5,050 tons) of soil, sediment, or sludge containing organic contaminants. The unit should also be considered for smaller sites when the other treatment alternatives, such as incineration, are costly.

Important assumptions regarding operating conditions and task responsibilities that could significantly affect the cost estimate results are presented in the following paragraphs.

4.3.1 Costs Excluded from Estimate

The cost estimates presented are representative of the charges typically assessed to the client by the vendor but do not include profit.

All costs associated with site preparation, system mobilization, startup, and demobilization have been excluded from the treatment cost. The costs for system mobilization, startup, and demobilization are incurred once at every site and are approximately the same regardless of the quantity of contaminated material present at the site. These costs are therefore presented individually as fixed costs. Site preparation costs are proportional to the amount of contaminated soil present at the site.

Many other actual or potential costs have also been excluded from this estimate. These costs are omitted because site-specific engineering designs beyond the scope of this SITE project would be required to determine those costs. As a result, certain functions are assumed to be the obligation of the responsible party or site owner and are not included in this estimate.

The costs that are assumed to be the responsible party's (or site owner's) obligation include the costs for items such as preliminary site preparation, obtaining permits, determining regulatory requirements, initiation of monitoring programs, waste disposal, conducting sampling and analyses, and post-treatment site cleanup and restoration. These costs tend to be site-specific and it is left to the reader to perform calculations relevant to each specific case. Whenever possible, applicable information is provided on these topics so the reader may perform calculations to obtain relevant economic data.

4.3.2 Maximizing Treatment Rate

Factors limiting the treatment rate include the feed rate and the online percentage. Increasing the feed rate and/or the online percentage can reduce the unit treatment cost. Online percentages of 60 percent, 70 percent, and 80 percent are compared in the following analysis. Increasing the feed rate beyond 186 tpd requires equipment modifications which are not considered in this analysis.

4.3.3 Utilities

To support the operation of the B.E.S.T.[®] system, a site must have clean water available at a flow rate of at least 1,020 gpd. The majority of this water (980 gpd) will be added to the extractor/dryer as direct steam. The remainder of the water will be used in other miscellaneous onsite applications including cleaning and rinsing.

Electrical power is required for the operation of many components of the B.E.S.T.[®] system. RCC projects that the full-scale unit will require 40 to 70 kilowatt-hours per ton of feed. For the purposes of this cost estimate, it is assumed that the average electricity consumption rate will be 55 kilowatt-hours per ton of feed.

For these cost calculations, it is assumed that sufficient water and electrical power are available at the site. The cost of preparing a site to meet these requirements can be high and is not included in this analysis. Costs associated with connecting the B.E.S.T.[®] system to the onsite water and electrical supplies are included in the site preparation costs, which are not included in the treatment cost.

4.3.4 Operating Times

It is assumed the treatment operations will be conducted 24 hours per day, 7 days per week. It is further assumed site preparation, assembly, shakedown (preliminary operation followed by adjustments to improve efficiency or functioning) and testing, and disassembly operations will be conducted 10 hours per day, 7 days per week. Excavation activities will be concurrent with treatment. Assembly, shakedown and testing, and disassembly are assumed to require 27 days, 18 days, and 30 days, respectively.

4.3.5 Labor Requirements

Treatment operations are assumed to require 18 onsite personnel: 12 system operators (4 per shift), 3 operations supervisors (1 per shift), and 3 safety personnel (1 per shift). RCC projects that six of the

onsite personnel will be employees from RCC's main office who will collect per diem and will require rental cars. Per diem and rental car allowances will not be required for the other 12 onsite personnel, who will be local hires. It is assumed that onsite personnel will work in three shifts for 24-hour-per-day, 7-day-per-week operation. Three administrative and clerical personnel will also be required. It is assumed that these employees will work 40 hours per week and will not be located onsite. Per diem and rental car allowances are therefore not included for administrative or clerical personnel.

4.3.6 Capital Costs

It is assumed that the full-scale B.E.S.T.[®] system will be owned and operated by RCC. It is further assumed that capital costs incurred by RCC will be distributed across the useful life of the system and passed on to the users. Capital costs are estimated for all major equipment included in the B.E.S.T.[®] system. Specific items include 11 process tanks, 3 extractor/dryers, 2 boilers, cooling towers, an air compressor/dryer, a centrifuge, an oil decanter, a solvent evaporator, a solvent decanter, a water stripper, a chiller, 4 heat exchangers, 3 trailers, and storage equipment.

4.3.7 Equipment and Fixed Costs

Annualized equipment cost, and costs that are estimated as percentages of equipment costs on an annual basis, have been prorated for the duration of time that the equipment is onsite. The costs for equipment, insurance, and taxes accrue during assembly, shakedown and testing, treatment, and disassembly. The per ton treatment cost, however, includes only the portions of these costs which accrue during treatment. Contingency costs and facility modification, repair, and replacement costs accrue only during treatment and are included in the per ton treatment cost.

4.4 Basis of Economic Analysis

The cost analysis was prepared by breaking down the overall cost into 12 categories. The categories, some of which do not have costs associated with them for this particular technology, are:

- Site preparation costs
- Permitting and regulatory costs
- Equipment costs
- Startup and fixed costs
- Labor costs
- Supplies costs

- Consumables costs
- Effluent treatment and disposal costs
- Residuals and waste shipping, handling, and transport costs
- Analytical costs
- Facility modification, repair, and replacement costs
- Site demobilization costs

The 12 cost factors examined as they apply to the B.E.S.T.® solvent extraction system, along with the assumptions employed, are described in the following subsections.

4.4.1 Site Preparation Costs

It is assumed that preliminary site preparation will be performed by the responsible party (or site owner). The amount of preliminary site preparation will depend on the site. Site preparation responsibilities include site design and layout, surveys and site logistics, legal searches, access rights and roads, preparations for support and decontamination facilities, and auxiliary buildings. Since these costs are site-specific, they are not included as part of the site preparation costs in this cost estimate.

Collection of the contaminated material (by excavation or dredging) is considered RCC's responsibility. Dredging costs for sediment typically range from \$7 to \$10 per cubic yard. Excavation costs are estimated to be approximately \$36 per ton of soil excavated. The estimated excavation costs are based on rental costs for operated heavy equipment, labor charges, and equipment fuel costs. It is assumed the minimum rental equipment required to achieve the design excavation rate of 18.2 tph includes six excavators, two box dump trucks, and two backhoes. The operation of this equipment will consume approximately 28 gallons of diesel fuel per hour. This cost estimate assumes that excavation activities will be conducted 40 hours per week. Excavation costs are itemized in Table 3. Costs associated with excavation or dredging are not included in the estimated per ton treatment cost.

Table 3. Excavation Costs

Item	Cost
Excavator	\$1,260/week
Box dump truck	\$525/week
Backhoe	\$585/week
Supervisor	\$40/hour
Excavator operator	\$30/hour
Dump truck operator	\$30/hour
Backhoe operator	\$30/hour
Diesel fuel	\$0.90/gallon

Certain other site preparation activities will be required at all sites. RCC will assume responsibility for the construction of foundations to support the B.E.S.T.® process and all auxiliary equipment. It is assumed that the responsible party or site owner will ensure that adequate electrical power and water supplies are available at the site. RCC will be responsible for utility lines and connections within the treatment area. RCC estimates a site preparation cost of \$100,000 for foundations, electrical power, and water. This cost is not included in the per ton treatment cost.

4.4.2 Permitting and Regulatory Costs

Permitting and regulatory costs are generally the obligation of the responsible party (or site owner), not of the vendor. These costs may include actual permit costs, system monitoring requirements, and/or the development of monitoring and analytical protocols. 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, this may be a significant factor since permitting activities can be both expensive and time-consuming.

4.4.3 Equipment Costs

Major pieces of equipment include the following:

- Eleven process tanks
- Three extractor/dryers
- Two boilers
- Cooling tower(s)
- Air compressor/dryer
- Centrifuge
- Oil decanter
- Solvent evaporator
- Solvent decanter
- Water stripper
- Chiller
- Four heat exchangers
- Three trailers
- Storage equipment

Equipment costs also include freight, sales tax, shop fabrication, instrumentation, and electrical systems. Cost estimates are based on vendor quotes obtained by RCC, on independently obtained vendor quotes, and on information from *Plant Design and Economics for Chemical Engineers* by M.S. Peters and K.D. Timmerhaus, Third and Fourth Editions [1][2]. The total equipment costs (including the purchase cost of the equipment, sales tax, freight, installation, instrumentation, and electrical systems) are estimated to

be approximately \$4,613,000 and the useful life of the system is estimated to be 10 years. After 10 years, it is assumed that the equipment will have a scrap value of 10 percent of its original purchase cost of approximately \$2,856,000. This yields an annualized equipment cost (based on straight-line depreciation) of approximately \$433,000.

Depending on the nature of the feed stream, pretreatment equipment may also be required. Pretreatment equipment is assumed to consist of a hammermill and a vibrating screen. The purchase cost for these items is estimated to be approximately \$74,700.

It is assumed no rental equipment will be required for operation. Support equipment is included in the equipment costs provided above. Support equipment refers to pieces of purchased equipment necessary for operation but not integral to the system.

The projected full-scale B.E.S.T.[®] solvent extraction system will be capable of treating 186 tpd of contaminated soil, sediment, or sludge. System effluents will include oversized residuals (if oversized materials are present in the feed), the treated solids, an oil product, and an aqueous product. It is projected that the aqueous product will be suitable for discharge to a municipal or industrial wastewater treatment facility.

The annualized equipment cost is prorated to the actual time the system is commissioned to remediate a contaminated material (including assembly, shakedown and testing, treatment, and disassembly). The portion of this cost that is accrued during treatment is then normalized relative to tons of feed treated and incorporated into the per ton treatment cost. The equipment costs accrued during assembly, shakedown and testing, and disassembly are included in the estimated costs for those functions.

4.4.4 Startup and Fixed Costs

Mobilization includes both transportation and assembly. The B.E.S.T.[®] system will be transportable, but it is large and its relocation will therefore require a significant amount of time and planning. For the purpose of this estimate, transportation costs are included with mobilization rather than demobilization activities. Transportation activities include moving the system, the solvent, and the workers to the site. As a rough estimate, it is assumed that the commercial-scale B.E.S.T.[®] system can be transported in 11 truckloads. Assembly (field installation) consists of unloading the system from the trucks and trailers and reassembling it. RCC estimates a total mobilization cost (transportation and assembly) of \$500,000, which is not included in the per ton treatment cost.

This cost estimate assumes that 18 days of shakedown and testing will be required after assembly and prior to the commencement of treatment. During this time, the system components are tested individually. It is estimated that eight workers will be required for 10 hours per day, 7 days per week during shakedown and testing. Labor costs consist of wages (\$40 per hour for the supervisor and \$30 per hour for the other seven operating personnel) and living expenses (refer to subsection 4.4.5). Labor costs during shakedown and testing are estimated to be \$55,980 and are not included in the per ton treatment costs.

Equipment costs, insurance costs, and property taxes accrued during assembly, shakedown, and testing are estimated to be approximately \$91,500. Because these costs are incurred during mobilization and startup, they are not included in the per ton treatment cost.

Working capital is the money required for the operation of the system [1]. For remediation projects, the working capital is the money that the vendor has spent in the operation of the system but has not yet recovered from the site owner or responsible party. For this estimate, working capital consists of the money invested in supplies, energy, spare parts, and labor costs for 1 month. For the calculation of working capital, 1 month is defined as one-twelfth of a year, or approximately 30.4 working days. At the end of a project, all working capital should be recovered. As a result, the only charge to the project is the "time-value" of the working capital over the period of the project. This cost is estimated based on the current prime lending rate of 6 percent.

The annual cost for insurance is estimated as 6 percent of the purchased equipment cost, and the annual cost for property tax is estimated as 3 percent of the total equipment cost [1]. Costs for insurance and taxes accrue during assembly, shakedown and testing, treatment, and disassembly. The per ton treatment cost, however, includes only the portions of these costs which accrue during treatment.

The cost for the initiation of monitoring programs has not been included in this estimate. Depending on the site, local authorities may impose specific guidelines for monitoring programs. The stringency and frequency of monitoring required may have a significant impact on the project costs.

An annual contingency cost of 10 percent of the annualized equipment capital costs is allowed to cover additional costs caused by unforeseen or unpredictable events, such as strikes, storms, floods, and price variations [1]. The annual contingency cost has been prorated to the treatment time and is included in the per ton treatment cost.

4.4.5 Labor Costs

Labor costs consist of wages and living expenses. Onsite personnel requirements per shift during treatment are estimated at: four operators at \$30 per hour, one operations supervisor at \$40 per hour, and one safety officer at \$40 per hour. Labor costs also include three administrative and clerical employees, each working 40 hours per week at \$20 per hour. Labor rates include benefits and overhead costs. It is assumed that onsite personnel will work in three shifts for 24-hour-per-day, 7-day-per-week operation.

Living expenses depend on several factors: the duration of the project, the number of local workers hired, and the geographical location of the project. RCC projects that they will send 6 people from their main office and the other 12 onsite personnel will be local hires. Living expenses for all onsite personnel who are not local hires consist of per diem and rental cars, both charged at 7 days per week for the duration of the treatment. Per diem covers hotel, food, and incidental expenses. For this analysis, per diem is assumed to be \$70 per person per day. This value is based on a rough average of the government per diem rates [3], which vary by location. Two rental cars are required for 24-hour-per-day operation and are available for an estimated \$25 per day per car. Depending on the location and length of the project, RCC may elect to hire and train more or fewer local personnel. Labor costs must be adjusted accordingly.

4.4.6 Supplies Costs

For this estimate, supplies consist of chemicals and spare parts. RCC estimates that 1 to 2 pounds of triethylamine will be required per ton of waste processed. The more conservative estimate of 2 pounds of triethylamine is used for this analysis. Triethylamine can be purchased in 330-pound drums for approximately \$1.40 per pound.

During the SITE demonstration, approximately 3 gallons of 50 percent sodium hydroxide were consumed per ton of waste treated. Although sodium hydroxide requirements will be site-specific, the economic analysis is based on the level of consumption measured during the demonstration. A sodium hydroxide cost of \$2.33 per gallon is used for the economic analysis [4].

Nitrogen gas is also used in the B.E.S.T.® system. RCC states that nitrogen costs typically range from \$1.00 to \$1.50 per ton of waste treated. For the purpose of this cost estimate, the assumed nitrogen cost is \$1.50 per ton of feed processed.

The annual cost for spare parts is estimated at 5 percent of the total purchased equipment cost [1].

4.4.7 Consumables Costs

Compressed instrument air will be produced by an air compressor/dryer system that will be transported to the site with the B.E.S.T.® system. As a result, compressed air costs are indirectly included elsewhere (in the electricity and equipment costs).

RCC estimates that the process will consume 40 to 70 kilowatts of electricity per ton of feed. For the purposes of this economic analysis, an average electricity consumption rate of 55 kilowatts per ton of feed is assumed. The average price of electricity sold to all ultimate consumers in the United States in April 1992 was \$0.066 per kilowatt-hour [5]. This average price was used in this economic analysis.

It is estimated that the operation of the B.E.S.T.® system will consume approximately 1,020 gpd of water during treatment. A water cost of \$0.0011 per gallon is used in this economic analysis.

4.4.8 Effluent Treatment and Disposal Costs

Effluent treatment and disposal costs vary depending upon the contaminants initially present in the soil, sediment, or sludge. As a result, effluent treatment and disposal costs are site-specific and are assumed to be the responsibility of the responsible party or site owner. The effluent streams from the B.E.S.T.® process include the treated solids, oversized feed material, an oil product, and an aqueous product. If the untreated soil, sediment, or sludge contains only organic contaminants that can be removed effectively, the treated material should be suitable for return to the site or use as backfill. If, however, there are leachable inorganic contaminants present or there are excessive quantities of organics remaining in the solids, the treated solids may require further treatment or disposal as a hazardous waste. The quantity and characteristics of the oversized materials will vary from site to site. At some sites, they may require treatment or disposal as a hazardous waste. The organic contaminants from the soil, sediment, or sludge are concentrated into the oil product. Incineration is the most likely disposal option for the oil. The cost of incineration varies depending on the specific organic contaminants present and the heating value of the oil product. The aqueous effluent from the B.E.S.T.® system should be suitable for discharge to a sanitary or industrial wastewater treatment facility.

4.4.9 Residuals and Waste Shipping, Handling, and Transport Costs

The residuals from the B.E.S.T.® process are the treated soil, sediment, or sludge; oversized feed materials; an oil product; and an aqueous product. Potential treatment and disposal options for these residuals are described in subsection 4.4.8. Other potential costs for each of these residuals include the costs associated with storage, handling, and transportation. These costs are assumed to be the obligation of the responsible party (or site owner) and could significantly add to the total cleanup cost, especially for TSCA or RCRA regulated residuals.

4.4.10 Analytical Costs

No analytical costs are included in this cost estimate. Much of the monitoring, sampling, and analyses required for full-scale treatment will be site-specific and will depend on the contaminants present and the cleanup standards. The client may elect or may be required by local authorities to conduct additional sampling and analysis. Analytical costs typically contribute significantly to the overall cost of a remediation project.

4.4.11 Facility Modification, Repair, and Replacement Costs

For estimating purposes, total annual maintenance costs (labor and materials) are assumed to be 10 percent of annualized equipment costs. Maintenance labor typically accounts for two-thirds of the total maintenance costs and has previously been accounted for in subsection 4.4.5. Maintenance material costs are estimated at one-third of the total maintenance cost and are prorated over the entire period of treatment. Costs for design adjustments, facility modifications, and equipment replacements are included in the maintenance costs.

4.4.12 Site Demobilization Costs

Demobilization costs are limited to costs associated with the disassembly and decontamination of the B.E.S.T.® system and auxiliary equipment; transportation costs are accounted for under mobilization activities. Disassembly consists of taking the B.E.S.T.® system apart and loading it and all auxiliary equipment onto 11 trailers for transportation. It requires the use of an operated 50-ton crane, available at \$6,360 per week, for 4 weeks. Additionally, disassembly requires an eight-person crew working 10 hours per day, 7 days per week, for 30 days. Labor costs consist of wages (\$40 per hour for the supervisor and \$30 per hour for each of the other workers) and living expenses (refer to subsection 4.4.5).

Equipment costs, insurance costs, and property taxes accrued during demobilization are estimated to be approximately \$61,000. Total demobilization costs are estimated to be approximately \$180,000 and are not included in the per ton treatment cost.

Site cleanup and restoration are limited to the removal of all equipment from the site; this is included in the cost of disassembly and decontamination. Requirements regarding the filling, grading, or recompaction of the soil will vary depending on the future use of the site and are assumed to be the obligation of the responsible party (or site owner).

4.5 Results of Economic Analysis

The costs associated with the operation of the B.E.S.T.® system, as presented in this economic analysis, are defined by 12 cost categories that reflect typical cleanup activities encountered on Superfund sites. Each of these cleanup activities is defined and discussed, forming the basis for the cost analysis presented in Table 4. The percentage of the total cost contributed by each of the 12 cost categories is shown in Table 5.

Online factors of 60 percent, 70 percent, and 80 percent are used to estimate the cost of treatment using the B.E.S.T.® system. The online factor is used to adjust the unit treatment cost to compensate for the fact that the system is not online constantly because of maintenance requirements, breakdowns, and unforeseeable delays. Through the use of the online factor, costs incurred while the system is not operating are incorporated into the unit cost.

Manufacturers provided RCC with projected preventive maintenance and repair requirements for the centrifuge and the extractor/dryers. Downtime due to repairs and preventive maintenance for other equipment was estimated by RCC based on pilot-plant experience. Projected maintenance and repair requirements are summarized in Table 6. These requirements are expected to represent a significant portion of the total system downtime. The totals shown in Table 6 assume that preventive maintenance tasks for the various pieces of equipment are planned and can therefore be conducted concurrently. Repairs, on the other hand, are often unplanned and therefore not conducted concurrently.

On an annual basis, RCC projects a total of 1,108 hours of downtime due to preventive maintenance and repairs. This represents approximately 13 percent of the total operating time available in 1 year. The system is likely to experience additional downtime due to other unfore-

Table 4. Treatment Costs for 186-tpd B.E.S.T.® System Treating Contaminated Soil, Sediment, or Sludge

Item	Cost (\$/ton)		
	60% online	70% online	80% online
Site Preparation	a	a	a
Permitting and Regulatory Costs	b	b	b
Equipment Cost Incurred During Treatment	10.62	9.11	7.97
Startup and Fixed Costs ^c	9.13	7.85	6.90
Labor	48.14	41.27	36.11
Supplies	15.40	14.84	14.46
Consumables	28.48	28.48	28.48
Effluent Treatment and Disposal	b	b	b
Residuals Shipping, Handling, and Transport	b	b	b
Analytical Costs	b	b	b
Facility Modification, Repair, and Replacement	0.35	0.30	0.27
Site Demobilization	d	d	d
Total Treatment Costs	112.12	101.85	94.19

- a Site preparation costs are not included in these per ton treatment costs. Preliminary site preparation costs are considered site-specific costs which are the responsibility of the site owner or responsible party. Other site preparation costs (excavation or dredging of contaminated materials, construction of a foundation for the B.E.S.T.® system, and electrical and water lines and connections within the treatment area) are considered RCC's responsibility and are presented individually. The costs for the foundation and for the electrical and water lines and connections are estimated to total approximately \$100,000. Excavation costs are estimated to be approximately \$36 per ton of soil excavated and dredging costs are estimated to be approximately \$7 to \$10 per cubic yard of sediment collected.
- b Considered a site-specific cost which is the responsibility of the site owner or responsible party and therefore not included in these per ton treatment costs.
- c Startup costs are presented individually and therefore not included in these per ton treatment costs.
- d Considered a fixed cost which is presented individually and therefore not included in these per ton treatment costs. The cost for site demobilization is estimated to be approximately \$180,000.

Table 5. Treatment Costs as Percentages of Total Costs for 186-tpd B.E.S.T.® System Treating Contaminated Soil, Sediment, or Sludge

Item	Cost (as % of total cost)		
	60% online	70% online	80% online
Site Preparation	a	a	a
Permitting and Regulatory Costs	b	b	b
Equipment Cost Incurred During Treatment	9.5	8.9	8.5
Startup and Fixed Costs ^c	8.1	7.7	7.3
Labor	42.9	40.5	38.3
Supplies	13.7	14.6	15.4
Consumables	25.4	28.0	30.2
Effluent Treatment and Disposal	b	b	b
Residuals Shipping, Handling, and Transport	b	b	b
Analytical Costs	b	b	b
Facility Modification, Repair, and Replacement	0.3	0.3	0.3
Site Demobilization	d	d	d

- a Site preparation costs are not included in these per ton treatment costs. Preliminary site preparation costs are considered site-specific costs which are the responsibility of the site owner or responsible party. Other site preparation costs (excavation or dredging of contaminated materials, construction of a foundation for the B.E.S.T.® system, and electrical and water lines and connections within the treatment area) are considered RCC's responsibility and are presented individually. The costs for the foundation and for the electrical and water lines and connections are estimated to total approximately \$100,000. Excavation costs are estimated to be approximately \$36 per ton of soil excavated and dredging costs are estimated to be approximately \$7 to \$10 per cubic yard of sediment collected.
- b Considered a site-specific cost which is the responsibility of the site owner or responsible party and therefore not included in these per ton treatment costs.
- c Startup costs are presented individually and therefore not included in these per ton treatment costs.
- d Considered a fixed cost which is presented individually and therefore not included in these per ton treatment costs.

Table 6. Projected Annual Downtime

Major Equipment Item	Preventative Maintenance, hours per year	Repairs, hours per year
Extractor/dryer	24	300
Centrifuge	30	408
Other Major Equipment	200	200
All Equipment Combined	200	908

seeable delays. As a result, online factors of less than 87 percent appear to be appropriate.

The projected results of commercial-scale operation are based on the results of the pilot-scale demonstration. Cost estimates for several pieces of equipment are based on quotes obtained from vendors by RCC or on independently obtained vendor quotes. Other cost estimates are based on information provided in *Plant Design and Economics for Chemical Engineers* [1][2]. When necessary, the "six-tenths" rule is used to estimate equipment costs from available cost data for equipment of a different capacity [1]. In other cases, the Chemical Engineering Cost Index is used to estimate current costs (August 1992) from earlier cost data [1].

It is assumed the commercial-scale unit will have a feed rate of 186 tpd. For the remediation of contaminated soil, sediment, or sludge, the results of the economic analysis show a unit cost ranging from \$94 per ton to \$112 per ton for 80 and 60 percent online conditions, respectively. These costs are considered "order-of-magnitude" estimates as defined by the American Association of Cost Engineers. The actual cost is expected to fall between 70 percent and 150 percent of these estimates. Since these cost estimates are based on a preliminary design, the range may actually be wider.

The cost estimates presented in Table 4 do not include costs associated with site preparation, system mobilization, startup, or demobilization. These costs will impact the total remediation cost. This impact will be more noticeable for small sites, where the total treatment costs will be low and the other costs will therefore represent a larger fraction of the total cost. The impact of these costs on the total remediation cost is less significant for large sites.

The cost estimates presented in Table 4 also exclude certain site-specific costs assumed to be the responsibility of the site owner or responsible party. These costs are described in subsections 4.3 and 4.4. This analysis does not include values for 6 of the 12 cost categories, so the actual cleanup costs incurred by the

site owner or responsible party may be significantly higher than the costs shown in this analysis. A summary of the items which are and are not included in the treatment cost is presented in Table 7.

Table 7. Costs Included in Treatment Cost

Item	Included in Treatment Cost?
Costs for Collection of Contaminated Material (by Excavation or Dredging)	no
Site Preparation Costs	no
Permitting and Regulatory Costs	no
Equipment Costs Incurred During Treatment	yes
Equipment Costs Incurred During Startup and Demobilization	no
Startup Costs (Costs Associated with Transportation, Assembly, Shakedown, and Testing)	no
Fixed Costs Incurred During Treatment	yes
Fixed Costs Incurred During Startup and Demobilization	no
Labor Costs Incurred During Treatment	yes
Labor Costs Incurred During Startup and Demobilization	no
Cost for Supplies	yes
Cost for Consumables	yes
Effluent Treatment and Disposal Costs	no
Residuals Shipping, Handling, and Transport Costs	no
Analytical Costs	no
Facility Modification, Repair, and Replacement Costs	yes
Site Demobilization Costs	no

4.6 References

1. Peters, M.S. and Timmerhaus, K.D. *Plant Design and Economics for Chemical Engineers*; Third Edition; McGraw-Hill, Inc: New York, 1980.
2. Peters, M.S. and Timmerhaus, K.D. *Plant Design and Economics for Chemical Engineers*; Fourth Edition; McGraw-Hill, Inc: New York, 1991.
3. Federal Register, Rules and Regulations. Volume 57 Number 39. February 27, 1992.
4. Chemical Marketing Reporter. Schnell Publishing Company, New York. October 12, 1992.
5. Energy Information Administration. Monthly Energy Review. DOE/EIA-0035 (92/07). July 1992.

Appendix A

Process Description

A.1 Introduction

Resources Conservation Company's (RCC's) Basic Extractive Sludge Treatment (B.E.S.T.®) solvent extraction system uses a unique property of certain amine solvents such as triethylamine to separate oil-contaminated sludges or soils into their oil, water, and solids fractions. Organic contaminants in the sludge or soil concentrate in the oil fraction after separation. The physical property of inverse miscibility of triethylamine in water can be used to overcome solvent extraction difficulties typically encountered when handling samples with high water content. At temperatures below 60°F, triethylamine is miscible with water (triethylamine and water are each soluble in the other). Above this temperature, triethylamine and water are only partially miscible. This physical property can be exploited by using triethylamine chilled below 60°F to solvate oil and water simultaneously [1].

During this Superfund Innovative Technology Evaluation (SITE) demonstration, the feedstock was mixed with triethylamine solvent to create a single phase extraction fluid. The liquid is a homogeneous solution of triethylamine and water present in the feedstock. This solution solvates the oils that were present in the feedstock, because the amine solvents can achieve intimate contact with solutes at nearly ambient temperatures and pressures. This is the reason that the B.E.S.T.® process is able to handle feed mixtures with high water content with a high extraction efficiency [1].

A.2 B.E.S.T.® Pilot Unit

The B.E.S.T.® pilot plant is a solvent extraction system designed for batch operation. A process flow diagram for the B.E.S.T.® system is shown in Figure A-1. Some of the unit process operations, such as water stripping and centrifugation, are normally operated continuously. The pilot plant has a nominal feed volume of 1 cubic foot (8 gallons) of dry solids per batch run [1]. Four operators per shift were employed for system operation,

process control, sample coordination, and safety considerations.

A.3 Unit Operations

The pilot plant operations, which will be described in this section, consist of the following [1]:

- Feed Preparation
- Extraction
- Decantation, Solvent Recovery, and Oil Processing
- Solids Drying
- Water Stripping
- Product Water Treatment

A.3.1 Feed Preparation

Feed preparation consists of sample collection, transport to the pretreatment area, and screening out of oversize material. The developer projects that screening to $\leq \frac{1}{2}$ -inch particle size will be recommended prior to treatment using the proposed full-scale B.E.S.T.® system [1]. During the SITE demonstration, samples were collected from two transects (Transects 6 and 28) along the Grand Calumet River by the U.S. Army Corps of Engineers (COE). After collection, the feed samples were transported to a storage area for pretreatment. The feed was screened to $\leq \frac{1}{8}$ -inch particle size using a vibrating screen. Enough material from each transect was screened to generate sufficient feed to allow at least five batches of each sample to be processed.

A.3.2 Extraction

The vessel used for the first extraction stage depends on the nature of the feed material. Material which has a high oil and/or water content is extracted first in the premix tank. Other material with low water and oil content is extracted first in the extractor/dryer vessel.

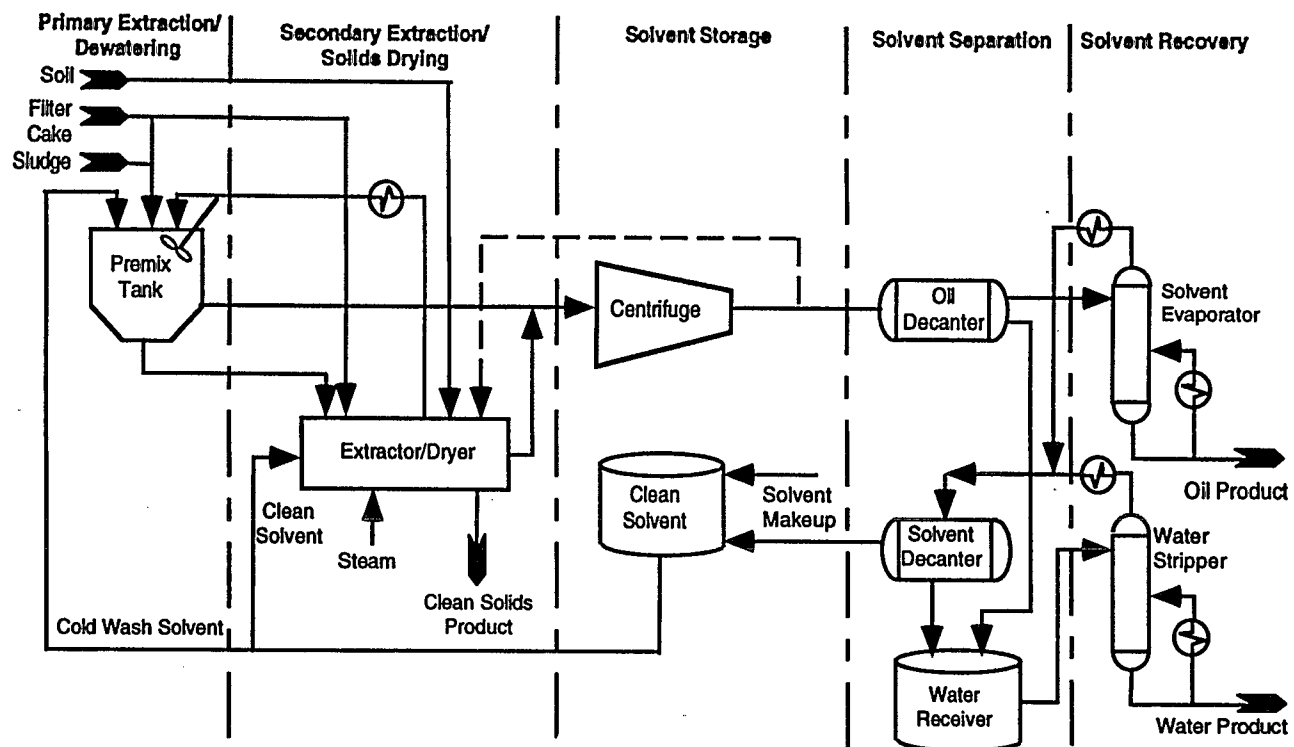


Figure A-1. Generalized Diagram of the B.E.S.T.® Solvent Extraction Process.

The sediments treated during this demonstration were first processed in the premix tank [1]. The first sediment extraction phase (a cold extraction) consisted of adding feedstock and a predetermined quantity of caustic to the premix tank, which was then filled with chilled solvent. The mixture was agitated for 5 to 30 minutes and allowed to settle. The minimum settling time was determined in the RCC laboratory prior to the demonstration [2]. The triethylamine/water/oil mixture was decanted through decant ports, located on one side of the premix tank, and drained to the decant pump which transported the mixture to the centrifuge. The fine solids were separated by centrifugation and directed to the extractor/dryer. The centrate was routed to the centrate tank and immediately pumped through the centrate filter into the solvent evaporator. Cold extractions were repeated and solids were accumulated as feed was added to the premix tank. Because the feed used in the SITE demonstration had a high moisture content (more than 40 percent), it required more than one cold extraction.

Once a sufficient volume of moisture-free solids is accumulated, the solids are transferred to a steam-jacketed extractor/dryer. Warm triethylamine is added to the solids. The mixture is heated, agitated, settled, and decanted. This process can also be repeated. These warm and hot extractions result in separation of the organics not removed during the initial cold extraction. The number of hot and cold extraction cycles required depends on feedstock composition and settling characteristics [1]. Feedstock processing requirements during the SITE demonstration were predetermined on a preliminary basis by bench-scale testing prior to the demonstration.

A.3.3 Decantation, Solvent Recovery, and Oil Processing

According to Figure A-1, the centrate recovered from the first extraction stage flows to the oil decanter, where it is separated into its aqueous and organic components. The aqueous phase is transferred to the water receiver tank. The organic phase, which contains a mixture of triethylamine, oil, and water, is pumped from the oil decanter to the solvent evaporator and heated. During the SITE demonstration, the oil decanter was not used because it was not functioning properly. The centrate was therefore pumped directly to the solvent evaporator. In either case, further heating in the solvent evaporator evaporates the low-boiling azeotrope of solvent and water (boiling point of approximately 170°F), leaving the oil behind. The evaporation process is continued until the water is depleted. At that point, the temperature of the boiling liquid rises until it reaches the boiling point of pure triethylamine (193°F) and evaporation continues until nearly all the triethylamine is removed [1].

The triethylamine/water vapor from the solvent evaporator is condensed in heat exchangers that use cooling water with a temperature of approximately 100°F. This produces condensed triethylamine/water with a temperature of approximately 110°F. At this temperature, the triethylamine and water are only partially miscible and separation is accomplished in a continuous flow solvent decanter. The recovered solvent is recycled back to the solvent storage tank and the water is drained by gravity to a water storage tank for storage until stripping operations are performed. Ultimately, the water is steam stripped in the water stripper column to remove residual triethylamine [1].

Oil processing is also performed in the solvent evaporator. The contents of the solvent evaporator are heated at approximately 193°F until virtually all the triethylamine is removed. The remaining residual solvent is released by the injection of a small amount of water into the oil. The water forms an azeotrope with the residual solvent, thereby dislodging it from the oil. The recovered oil fraction can be dechlorinated or incinerated to destroy the organics [1].

When the samples from Transect 28 were treated, the amount of oil produced was too small for oil processing, so the oil was left in solution with a limited amount of solvent. This oil/solvent mixture was stored in a drum for disposal. Oil processing was conducted on the oil product from the treatment of the Transect 6 sediments.

A.3.4 Solids Drying

Solids drying is performed on the solids remaining in the extractor/dryer after the last extraction stage. Before drying, a small amount of caustic is added to the solids for pH control. The extractor/dryer is equipped with a steam jacket and direct steam injection ports. To dry the washed solids, steam is first supplied only to the steam jacket to indirectly heat the extractor/dryer and its contents to about 170°F. After the bulk of the solvent is removed, direct steam is injected into the extractor/dryer vessel. The entire drying process is performed with the extractor/dryer mixing paddles rotating. This mixing increases the heat transfer, thus reducing the drying time. The solvent and steam form an azeotrope which is then directed to the dryer condenser. After all the triethylamine is removed, the temperature of the vapor rises to the boiling point of water. After the drying process is complete, the solids are removed through the discharge port on the bottom of the extractor/dryer [1]. During the SITE demonstration, a portion of the solids were retained for laboratory analysis and the remainder was collected for transfer to a polychlorinated biphenyl (PCB) disposal facility.

Liquid from the condenser drains into the mixing tank. The triethylamine/water mixture and any carryover dust are directed to the centrifuge to remove solids. The centrate is then pumped through the centrate filter and into the solvent evaporator, where it is combined with the triethylamine/oil/water already present [1].

A.3.5 Water Stripping

Water stripping is accomplished by direct contact steam stripping. Before the triethylamine is stripped from the decant water, a predetermined amount of caustic soda is added to the water to raise the pH. Steam is injected directly into the bottom of the stripping column to heat the column to the desired temperature. Preheated feed water is introduced into the top of the column. The non-vaporized feedwater flows through the column and is stripped of residual solvent by upflowing steam. The bottoms are returned to the water receiver tank until a steady state is obtained. The bottoms are then rerouted to be discharged as product water. The solvent azeotrope vapors generated are routed to the water stripper condenser and the recovered solvent is recycled [1].

A.3.6 Product Water Treatment

The final process involves the discharged stripped water, termed product water. During the SITE demonstration, this water was collected separately for each batch processed. These samples were analyzed for pH, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), oil and grease (O&G), residual solvent (triethylamine), conductivity, PCBs, polynuclear aromatic hydrocarbons (PAHs), and metals. Analytical results indicated that the product water was a RCRA waste because of its high pH. RCC claims that the high pH was due to operator error (addition of excessive caustic) and should not typically be an issue.

A.4 References

1. Resources Conservation Company. Draft B.E.S.T.® Pilot Unit Test Report, Grand Calumet River, Gary, Indiana, October 1992.
2. Science Applications International Corporation. Superfund Innovative Technology Evaluation - Draft Demonstration Plan, June 1992.

Appendix B

Vendor Claims

NOTE: This appendix to the Environmental Protection Agency's (EPA's) Applications Analysis Report was prepared by Resources Conservation Company (RCC). Claims and interpretations of results in this Appendix are those made by the vendor and are not necessarily substantiated by test or cost data. Many of RCC's claims regarding cost and performance can be compared to the available data in Section 4, Section 3, and Appendix C of this Applications Analysis Report.

RCC, the developer of the Basic Extractive Sludge Treatment (B.E.S.T.®) solvent extraction process, states that the B.E.S.T.® process offers several advantages over other treatment technology alternatives. These advantages include:

- The B.E.S.T.® process can effectively remove polychlorinated biphenyls (PCBs), polynuclear aromatic hydrocarbons (PAHs) and other hazardous organic compounds from soils, sludges and sediments.
- Triethylamine, the solvent used in the B.E.S.T.® process, is environmentally friendly. Triethylamine is biodegradable, does not accumulate in the environment, and occurs naturally in the food chain.
- There are no air emissions from the B.E.S.T.® process. Therefore, permitting and siting a B.E.S.T.® process unit is simpler than for other technologies, such as incineration or thermal desorption.

Discussion of these claims is presented in Subsections B.1, B.2, and B.3.

RCC conducted a B.E.S.T.® pilot-scale demonstration test on contaminated sediments from the Grand Calumet River in Gary, Indiana. Testing occurred in Gary, Indiana between June 23, 1992 and July 28, 1992. The test was performed to demonstrate the ability of the B.E.S.T.® process to remove PAHs and PCBs from contaminated sediments.

Sediment from two locations was tested. The locations were Grand Calumet River Transect 28 and Grand Calumet River Transect 6. Five batches of each sediment type were processed. The less contaminated sediment, Transect 28, was processed first.

During the demonstration program, RCC collected and analyzed numerous samples from the pilot unit when treating sediments from both Transect 6 and Transect 28. [RCC conducted these analyses in accordance with published EPA Quality Assurance/Quality Control (QA/QC) guidelines.] Subsection B.4 provides a comparison of the Superfund Innovative Technology Evaluation (SITE) analytical data and RCC analytical data. The SITE and RCC analytical results closely correlate, further substantiating the success of this demonstration program.

Subsection B.5 provides a comparison of the bench-scale treatability test data and the pilot-scale demonstration test data generated as part of this project. The comparison clearly shows that the bench-scale treatability test protocol closely predicts pilot-scale test results. Subsection B.5 also provides a comparison of bench-scale treatability test data to full-scale performance data from a previous project.

A summary of other pilot-scale demonstration tests conducted by RCC is provided in Subsection B.6. Results from these pilot-scale test projects demonstrate that the B.E.S.T.® solvent extraction process can effectively remove PCBs, PAHs and other hazardous organics from soils, sludges and sediments.

B.1 B.E.S.T.® Process Effectively Removes PCBs and PAHs from Sediment

This demonstration of the B.E.S.T.® solvent extraction process clearly shows that the technology can remove PCBs and PAHs from sediments with a high water content. The following objectives of the demonstration

program were successfully achieved:

- Demonstrate the B.E.S.T.® process unit operations at pilot scale. The unit operation components demonstrated included the following equipment:
 - Extractor/dryer vessel
 - Fines centrifuge
 - Decanter vessel
 - Solvent evaporator
 - Water stripper
- The pilot test will process enough contaminated sediment to evaluate the process sensitivity to changes in the feed composition between the two locations tested; Transect 6 and Transect 28.
- Demonstrate that the B.E.S.T.® process can achieve greater than 96 percent removal of total PAHs and total PCBs from the contaminated sediments.
- Produce recovered water, solids and oil with solvent residual concentrations of less than 80 parts per million (ppm), 150 ppm, and 1000 ppm, respectively.
- Calculate mass balance of feed material into the pilot unit versus total products out (solids, water and oil) within the range of 100 ± 15 percent.

Overall success of the demonstration test was excellent. RCC's analytical results for the sediments treated during the demonstration test are summarized in Figures B-1, B-2, B-3, and B-4.

B.2 B.E.S.T.® Process Solvent Is Environmentally Friendly

Triethylamine, the solvent used for the B.E.S.T.® solvent extraction process, has several characteristics that enhance its use for removing hazardous organics from the environment. These characteristics include:

- Triethylamine is biodegraded aerobically by commonly occurring soil bacteria.[1]
- Triethylamine photochemically degrades in the atmosphere, will not adsorb to sediments, and does not bioconcentrate in the environment.[2]
- Triethylamine appears in the food chain in boiled beef, caviar, cheeses, wheat bread, and milk fermentation products.[3]
- Triethylamine is produced from natural ingredients; ethyl alcohol and ammonia.[4]

- Triethylamine is a commonly used industrial solvent. Over 17 million pounds of triethylamine were produced in 1982.[5]

B.2.1 Triethylamine Is Biodegradable

As discussed in Appendix C, part C.8, Science Applications International Corporation (SAIC) conducted limited testing to assess the biodegradability of triethylamine in one treated solids sample. Samples of a single batch of treated solids were mixed in a 1 to 1 ratio with common potting soil. No bacteria cultures were taken to quantitate the bacterial activity in the potting soil. No attempt was made to produce an environment suitable for bacterial growth or biodegradation. Specifically, the elevated pH of the solid product was not neutralized, moisture content of the solid product and potting soil was not measured or adjusted, and no attempt was made to aerate the samples in this testing.

SAIC testing showed no observed difference between the triethylamine biodegradability in the control samples and the mixed soil samples. These results are too limited to be of any use in determining if triethylamine can be expected to biodegrade. The only valid conclusion that may be reached as a result of SAIC biodegradation testing is that if the treated solids were mixed 1 to 1 with potting soil, with no other environment adjustments and no product aeration, no significant biodegradation of triethylamine would be expected.

RCC studies have shown that neutralized samples with a moderate moisture content exhibit the ability to markedly reduce the triethylamine level by biodegradation when mixed with soils containing common soil bacteria [6]. Triethylamine levels were reduced by as much as 99 percent. Independent studies have also been conducted on the biodegradability of triethylamine. It has also been reported that triethylamine is degraded in an *Aerobacter* bacterial culture [1]. *Aerobacter* is a common soil bacteria. It has also been reported that triethylamine readily biodegrades in a brine acclimated waste treatment system [7].

B.3 B.E.S.T.® Process Has No Air Emissions

During the demonstration program SITE monitored the ambient air for organic vapors on a daily basis 5 meters

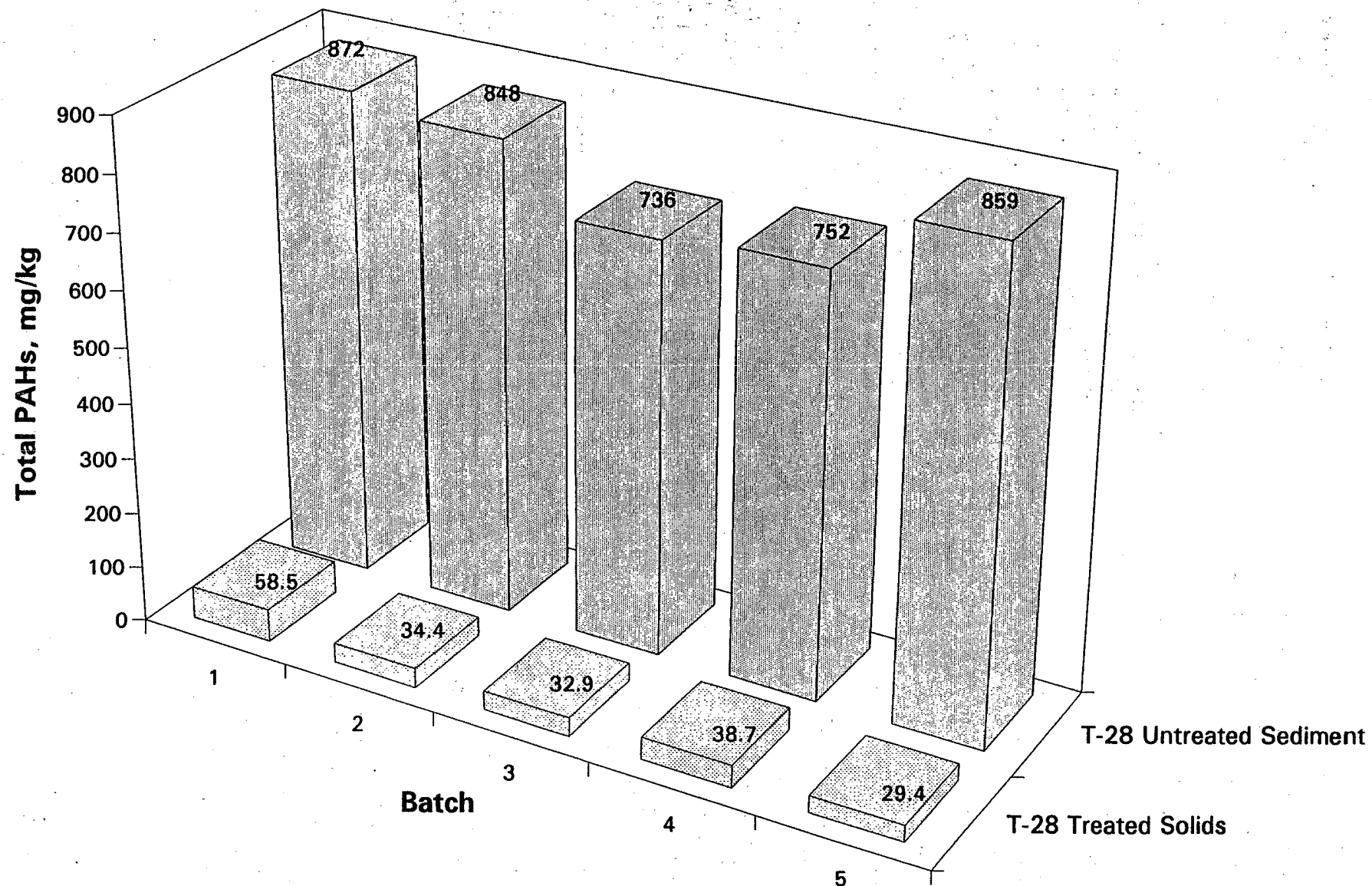


Figure B-1. Transect 28 PAH Summary.

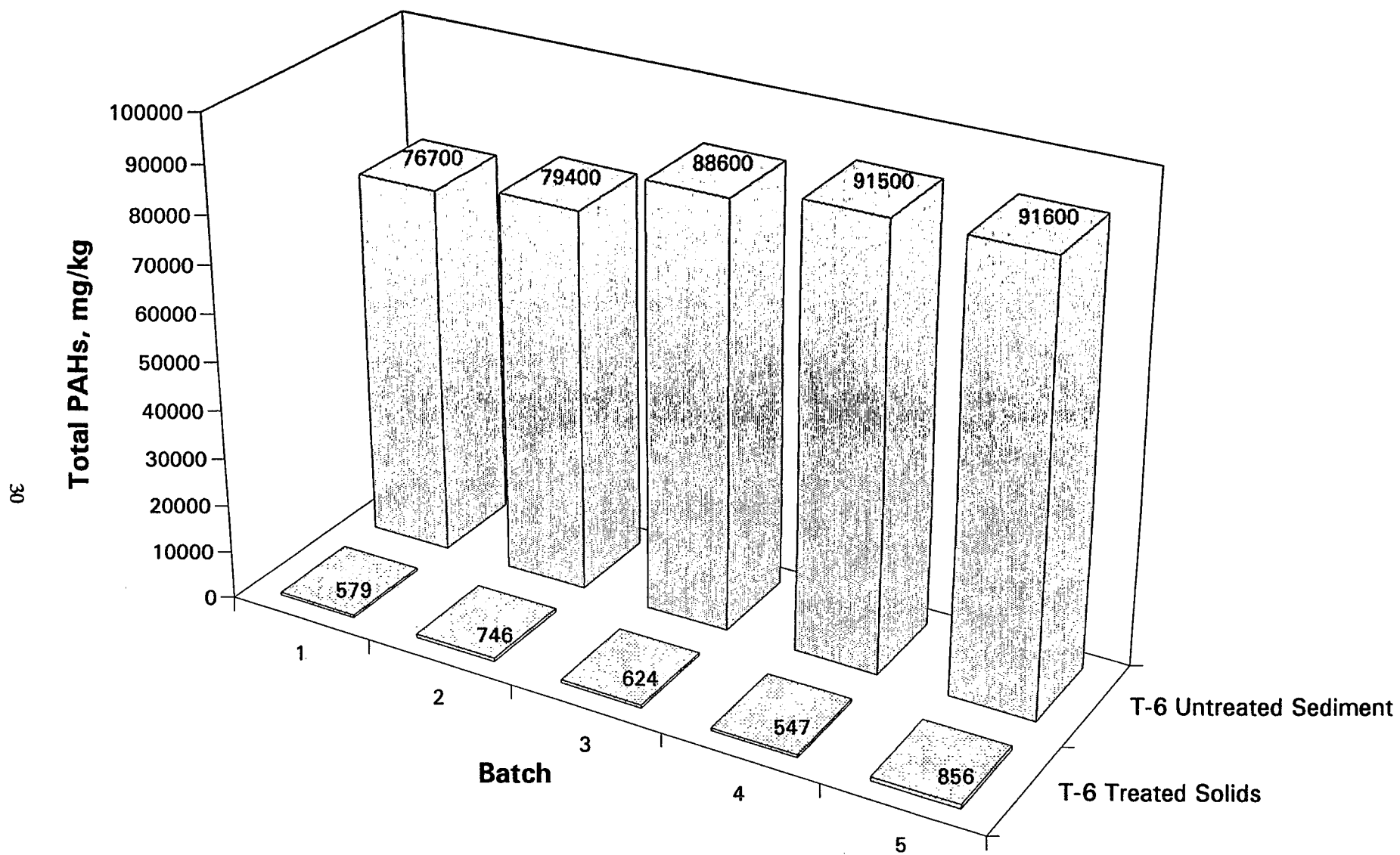


Figure B-2. Transect 6 PAH Summary.

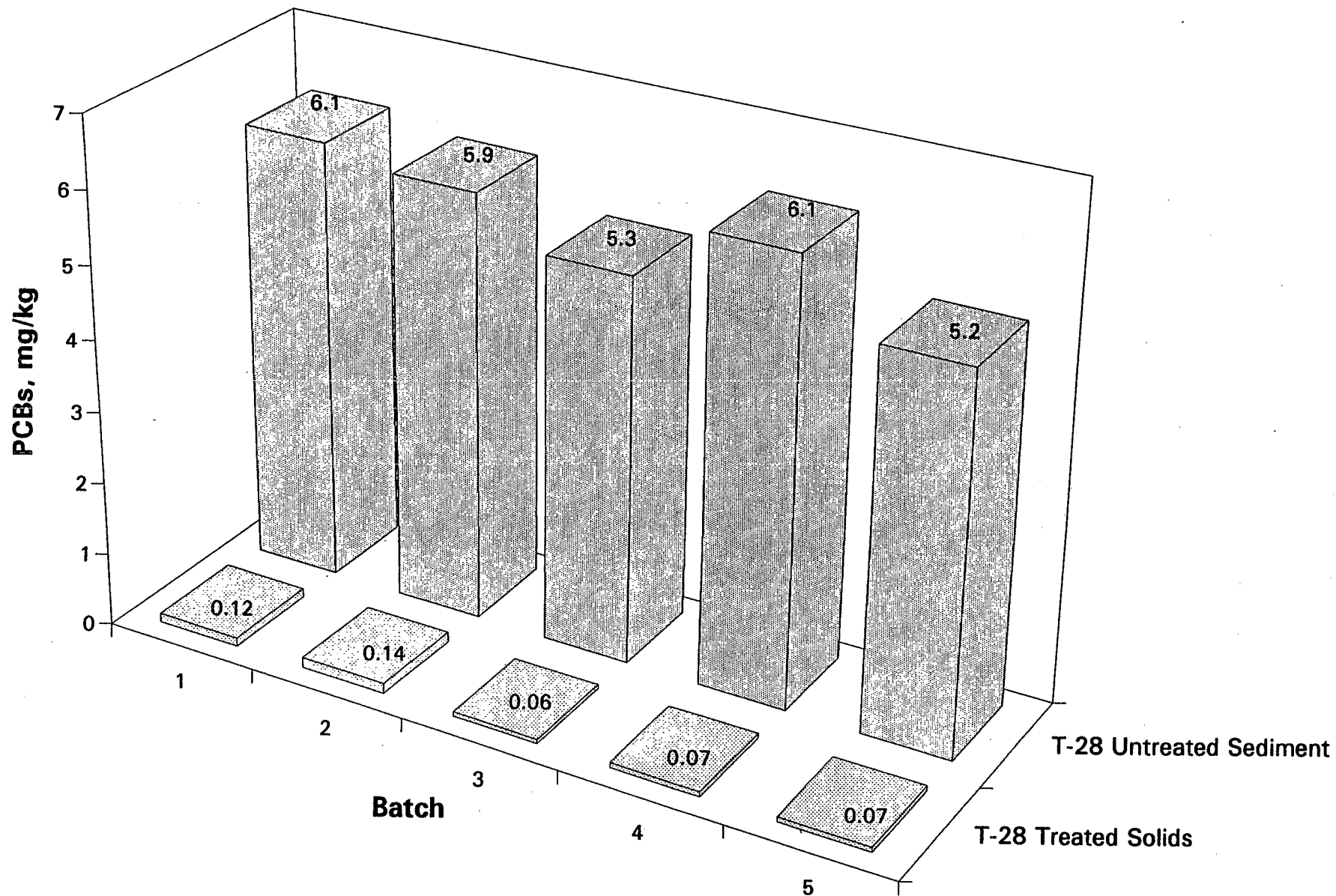


Figure B-3. Transect 28 PCB Summary.

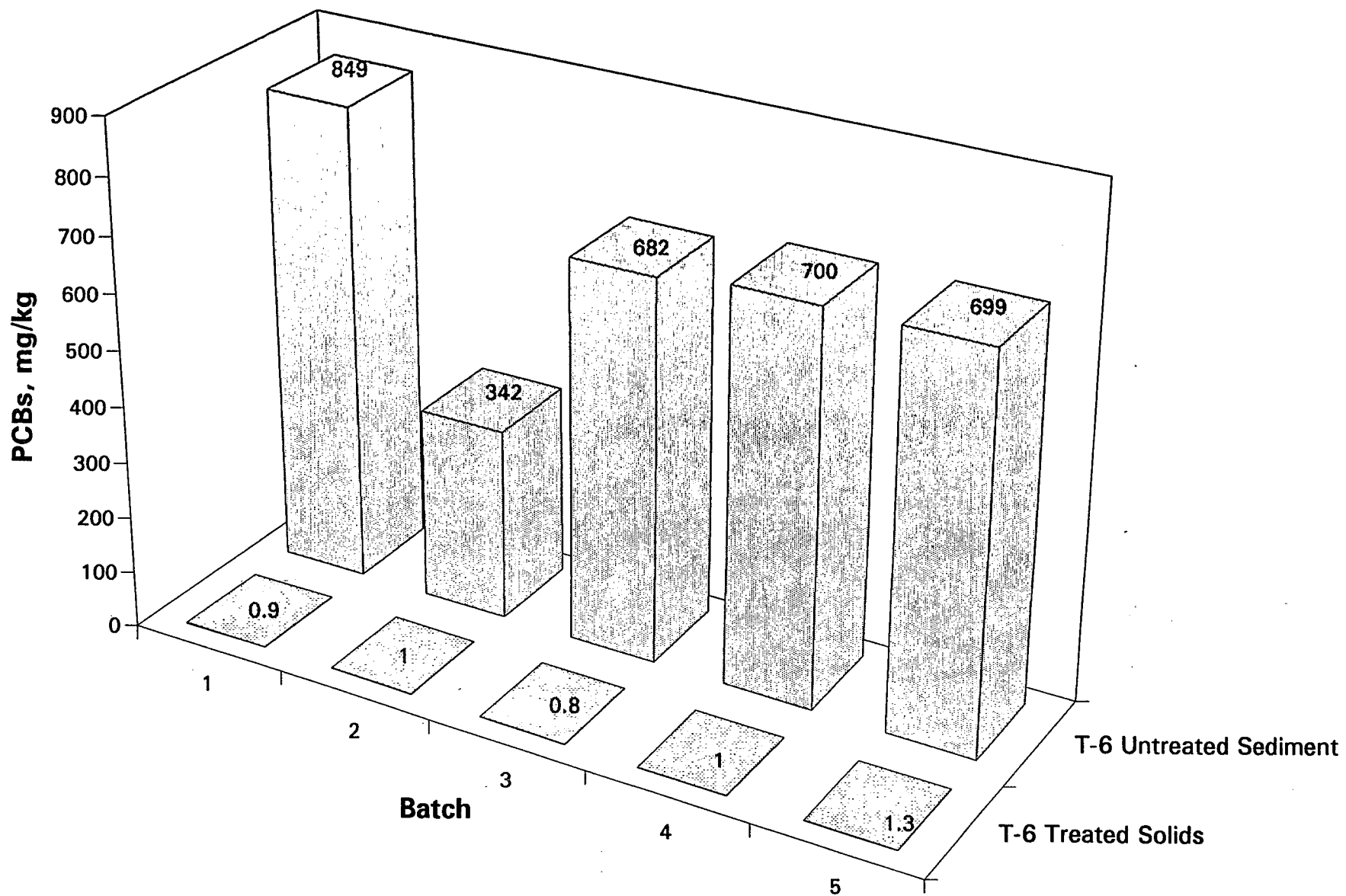


Figure B-4. Transect 6 PCB Summary.

upwind and downwind of the treatment unit. No organic vapors were detected during the demonstration program. SITE also monitored the vent gases from the treatment unit on a continuous basis. No solvent was detected in the vent gases released to the environment. Results of SITE's air monitoring operations are provided in Subsection C.7.

B.4 SITE and RCC Analytical Results Closely Correlate

SITE analytical results were in agreement with RCC analytical results. A comparison between SITE and RCC PAH and PCB analytical results follows in Tables B-1 and B-2:

Table B-1. SITE vs. RCC Analytical Results (PAH Results, mg/kg dry basis)

Sample	SITE Results	RCC Results
Transect 28		
Untreated Sediment	550	783
Treated Sediment	22	34
Removal Efficiency, percent	96.0	95.6
Transect 6		
Untreated Sediment	70,900	87,500
Treated Sediment	510	716
Removal Efficiency, percent	99.3	99.2

Table B-2. SITE vs. RCC Analytical Results (PCB Results, mg/kg dry basis)

Sample	SITE Results	RCC Results
Transect 28		
Untreated Sediment	12.1	5.5
Treated Sediment	0.04	0.07
Removal Efficiency, percent	99.7	98.7
Transect 6		
Untreated Sediment	425	580
Treated Sediment	1.8	1.1
Removal Efficiency, percent	99.6	99.8

B.4.1 Overall Mass Balance Results

The overall mass balances calculated by RCC were based on RCC's analytical results. The overall mass

balances calculated by SITE and RCC represent excellent mass balance closure. Both total mass balances indicate that even though individual balances may vary because of the considerable number of analyses involved, no significant amount of material is lost for either Transect 28 or Transect 6. The total mass balances for RCC and SITE are compared here in Table B-3:

Table B-3. Total Mass Balance Comparison

Sample	RCC Total Mass Balance	SITE Total Mass Balance
Transect 28, percent	103.5	99.3
Transect 6, percent	106.2	99.6

B.4.2 RCC QA/QC Requirements

RCC prepared a detailed Sampling Analysis Plan and Quality Assurance Project Plan in strict compliance with published EPA QA/QC guidelines. The QA/QC requirements for this demonstration project included:

- Data quality objectives
- Field sampling and measurement procedures
- Sample custody and transport
- Calibration procedures and frequency
- Sampling, analysis and monitoring
- Data validation
- Performance audits and system audits

B.5 B.E.S.T.[®] Process Performance Accurately Predicted by Bench-Scale Treatability Test Protocol

In order to evaluate each potential application for the B.E.S.T.[®] process, RCC has developed a low cost bench-scale treatability test protocol. This bench-scale test provides data that closely simulate both pilot-scale and full-scale system performance. The bench-scale treatability test data allow RCC to evaluate the feasibility of the process and to estimate treatment costs. When a pilot-scale test is performed, the bench-scale test is used to obtain information which provides operational guidelines.

B.5.1 Bench-Scale Test vs. Pilot-Scale Test Data for Grand Calumet River Testing

RCC performed bench-scale treatability testing with Grand Calumet River sediment, before pilot-scale testing began. Split samples of the exact material to be tested at the pilot scale were tested at the bench scale in June 1992. A summary of results from all testing shows

the ability of bench-scale testing to predict pilot-scale test results:

Table B-4. Transect 6 Testing Comparison (PAH and PCB Concentrations, mg/kg, dry basis)

Sample	PCBs	Total PAHs
Bench-Scale Test		
Untreated Sediment	700	76,900
Treated Solids	< 1	346
Removal Efficiency, percent	> 99.8	99.6
Pilot-Scale Test		
Untreated Sediment	580	87,500
Treated Solids	1.1	716
Removal Efficiency, percent	99.8	99.2

Table B-5. Transect 28 Testing Comparison (PAH and PCB Concentrations, mg/kg, dry basis)

Sample	PCBs	Total PAHs
Bench-Scale Test		
Untreated Sediment	6	890
Treated Solids	<1	28
Removal Efficiency, percent	>83	97
Pilot-Scale Test		
Untreated Sediment	5.5	783
Treated Solids	0.07	34
Removal Efficiency, percent	98.7	95.6

B.5.2 Bench-Scale Test vs. Full-Scale Remediation

The reliability of the bench-scale treatability tests to predict full-scale performance has been verified by the US EPA report *Evaluation of the B.E.S.T.® Solvent Extraction Sludge Treatment Technology- Twenty-Four Hour Test*, by Enviroresponse, Inc., under EPA Contract 68-03-3255. Evaluating the B.E.S.T.® process, this report states:

Resources Conservation Company has conducted many laboratory tests and developed correlations to which data from full-scale operations, such as the General Refining site, can be compared.

Table B-6 presents data from two separate bench-scale treatability tests and from full-scale operations at the

General Refining, Inc., Superfund site. All data were collected by an EPA contractor. These data demonstrate a close correlation between bench-scale treatability test data and full-scale operating data.

Table B-6. General Refining Site PCB Concentrations in Raw Sludge and Product Fractions (ppm)

	<u>Bench-Scale (1986)</u>		<u>Full-Scale</u>
	Test A	Test B	Processing (1987)
Raw Sludge, mg/kg, dry basis	14	12	13.5
Product Solids, mg/kg, dry basis	0.02	0.14	<0.13
Product Water, mg/L	<0.01	<0.01	<0.005
Extraction Efficiency, percent	99.9	98.8	>99

B.6 Other Pilot-Scale Test Project Results Substantiate SITE Demonstration Project Results

The Pilot Unit has been tested at four facilities prior to the SITE demonstration test. A brief summary of the results of those tests follows.

B.6.1 PCBs in Soils and Sediments at an Aluminum Manufacturing Site

PCBs were removed from soils and sediments at an aluminum manufacturing site. The treatment objective of 2 mg/kg was easily met. The following table summarizes the results:

Table B-7. Aluminum Manufacturing Facility PCB Removal From Soils and Sediments

Sample	<u>PCB Concentration (mg/kg, dry basis)</u>	
	Untreated Sample	Treated Solids
Lagoon #1 (sediment)	530	0.7
Lagoon #2 (soil)	800	1
Lagoon #3 (sediment)	480	1
Lagoon #4 (sediment)	137	0.6
Landfill #1 (soil)	13	0.3
Landfill #2 (soil)	5	0.2

B.6.2 PAHs in Sludge from Wood Treatment Facilities

PAHs were removed from two contaminated sediments taken from different wood treatment facilities. The

treatment goal of removal of greater than 90 percent of PAHs was easily met. The following table summarizes the results:

Table B-8. Wood Treatment Facilities PAH Removal From Sediments

Sample	Total PAH Concentration (mg/kg, dry basis)	
	Untreated Sample	Treated Solids
Bayou Bonfouca Site, Slidell, Louisiana	9700	23
Jennison-Wright Site, Granite City, Illinois	8800	79

B.6.3 PCBs in Soil at a Manufacturing Site

PCBs were removed from a soil sample at a manufacturing site in Greenville, Ohio. Approximately 1000 pounds of soil sample was treated in 18 distinct batches. The PCB contamination level in the sample was reduced from 130 mg/kg (dry basis) to 2 mg/kg (dry basis). The treatment objective of 10 mg/kg was easily met.

B.6.4 PAHs in Refinery Sludge

PAHs were removed from four contaminated sludges at the Exxon refinery, Baton Rouge, Louisiana. The sludges were tested to help establish Best Demonstrated Available Technology (BDAT) standards for removal of PAHs from K048-K052 wastes (refinery sludges). Current BDAT standards are partially based on results from this pilot testing.

The oil and grease content of the refinery sludges was reduced from 26 percent to 0.09 percent. Total PAHs were reduced to 11.6 mg/kg.

B.7 References

1. EPA Document EPA Data ORD USEPA Washington, D.C. 20460, Feb. 1983 Manual (reprint), Volume 1 600/2-82-001a (1983)
2. Howard, P.H. et al: Handbook of Environmental Fate and Exposure Data for Organic Chemicals pp 493-498 (1990)
3. Golonmya, R.V. et al: Chem Senses Flavour 4:97-105 (1979)
4. Kirk & Othmer: Encyclopedia of Chemical Technology (1980)
5. USITC: United States International Trade Commission, USITC 1982 (1986)
6. Erikson, T., Resources Conservation Company: Biodegradation of Triethylamine, (September 9, 1992)
7. Portier, R.J., Hoover, D., Fugisaki, K.: Evaluation of Biotreatment Approaches for Triethylamines and Methyl Isobutyl Ketones Waste Waters, Hi-Tek Polymers, Inc. Preliminary Study, Institute For Environmental Studies, Louisiana State University, Baton Rouge, LA, (July 1, 1991)

Appendix C

SITE Demonstration Results

C.1 Introduction

This appendix summarizes the results of the Superfund Innovative Technology Evaluation (SITE) demonstration test of the Resources Conservation Company (RCC) Basic Extractive Sludge Treatment (B.E.S.T.®) system. These results are also discussed in Sections 1 and 3 of this report. A more detailed account of the demonstration may be found in the Technology Evaluation Report (TER).

Test sediments were collected from two locations (Transect 28 and Transect 6) in the Grand Calumet River approximately 10 days before the start of the demonstration. Sediments were collected using hollow aluminum tubes that were driven approximately 5 feet into the soft river bottom. The sediment samples were emptied into 5-gallon buckets and transported to the demonstration site. Sediment from Transect 28 was screened and homogenized to form Sediment A, while sediment from Transect 6 was screened and homogenized to form Sediment B.

For the SITE demonstration, Sediment A and Sediment B were treated using the B.E.S.T.® pilot-scale system. Three runs (Runs 1, 2, and 3) were conducted for each sediment to optimize operating parameters. For each sediment, the operating parameters from one of the first three runs were selected as "optimum" and two more runs were conducted at optimum conditions. Optimum conditions for each sediment were determined by RCC based on observations, sampling, and analyses (by RCC's laboratory) from the three initial runs. For Sediment A, Runs 3, 4, and 5 were conducted at optimum conditions. For Sediment B, Runs 2, 4, and 6 were conducted at optimum conditions. The summarized results presented in Sections 1 and 3 are averages from the runs conducted at optimum conditions. During all runs, sampling was performed in accordance with the procedures outlined in the Demonstration Plan.

The primary objective of a SITE demonstration is to assess the ability of the technology to meet applicable or relevant and appropriate requirements (ARARs). The ability of the B.E.S.T.® system to remove organic contaminants from inorganic matrices such as soils and sludges was evaluated. Results from this demonstration include polynuclear aromatic hydrocarbon (PAH) concentrations in the treated and untreated sediment; polychlorinated biphenyl (PCB) concentrations in the treated and untreated sediment; triethylamine concentrations in the treated sediment, product oil, and product water; and metals leachability by the Toxicity Characteristic Leaching Procedure (TCLP) for the treated and untreated sediment. PAH and PCB concentrations in the product oil and product water are summarized in subsection C.6. Air emissions results for both the vent emissions and the ambient air are presented in subsection C.7. Finally, the results of the triethylamine biodegradability testing are presented in subsection C.8.

C.2 Contaminant Removal Efficiencies

During the demonstration, 96 percent of the PAHs and greater than 99 percent of the PCBs initially present in Sediments A and B were removed. These results are consistent with demonstration test objectives and support RCC's claims that average removal efficiencies of 96 percent to greater than 99 percent could be obtained for both PAHs and PCBs using the B.E.S.T.® system. Table C-1 lists the specific concentrations and removal efficiencies obtained during runs performed using optimum conditions. These results were obtained by comparing contaminant concentrations present in the sediments before and after treatment. Table C-1 also contains the oil and grease (O&G) removal efficiencies obtained during the demonstration test. Average O&G removal efficiencies of greater than 98 percent were experienced for both sediments. The measurement of O&G is not required for the evaluation of RCC's claims. However, because PCBs and PAHs are among the compounds detected by the analysis for O&G, these

Table C-1. Total PAH, Total PCB, and O&G Removal Efficiencies

Parameter	Total PCBs			Total PAHs			O&G		
	Raw Sediment mg/kg, dry	Treated Solids mg/kg, dry	Percent Removal	Raw Sediment mg/kg, dry	Treated Solids mg/kg, dry	Percent Removal	Raw Sediment mg/kg, dry	Treated Solids mg/kg, dry	Percent Removal
Sediment A									
Run 3	8.01	0.05	99.4	457	21	95	7,400	203	97.3
Run 4	11.8	0.04	99.7	568	28	95	6,600	66	99.0
Run 5	16.4	0.04	99.8	620	17	97	6,700	65	99.0
Average	12.1	0.04	99.7	548	22	96	6,900	111	98.4
Sediment B									
Run 2	316	2.1	99.3	64,100	447	99.3	116,000	1,330	98.9
Run 4	462	1.8	99.6	63,500	402	99.4	167,000	1,230	99.3
Run 5	497	1.4	99.7	85,200	682	99.2	99,100	1,810	98.2
Average	425	1.8	99.6	70,900	510	99.3	127,000	1,460	98.9

O&G results support the removals experienced for both PAHs and PCBs.

C.3 Residual Triethylamine

Treated solids produced during the optimum treatment runs for Sediment B had an average triethylamine concentration of 103 mg/kg. Water generated during these runs had a triethylamine concentration of 2.2 mg/L or less, while the oil product collected at the end of all Sediment B treatment runs had a triethylamine concentration of 733 mg/kg. Because very little oil product was generated during the treatment of Sediment A, the Sediment A oil product was not processed to reduce its triethylamine concentration. Solid product generated from the optimum treatment runs for Sediment A realized an average residual concentration of 45.1 mg/kg, while water products from the optimum treatment runs for Sediment A had triethylamine concentrations of 1.0 mg/L or less. These results comply with RCC's claims and the demonstration test objectives regarding the system's ability to produce residual triethylamine concentrations of less than 80, 150, and 1,000 parts per million (ppm) for water, solids, and oil products, respectively. Table C-2 lists the specific concentrations obtained for the three products generated during those runs performed under optimum conditions.

C.4 Mass Balances

Mass balances for Sediment A and Sediment B were performed for water, oil, solids, PCBs, and PAHs entering and exiting the system during system operation.

Table C-2. Residual Triethylamine Concentrations

Parameter	Solids mg/kg	Water mg/L	Oil mg/kg
Sediment A			
Run 3	27.8	<1	a
Run 4	28.0	<1	a
Run 5	79.6	2.2	a
Sediment B			
Run 2	88.7	1.0	a
Run 4	130	<1	a
Run 5	89.3	<1	733 ^b

a Not analyzed

b This number is an average value for five aliquots collected incrementally, following oil processing, at the end of the treatment of Sediment B.

These balances were obtained by comparing the weights and volumes of raw sediment and process additives (i.e., solvent, sodium hydroxide, etc.) entering the system with the various product fractions and samples recovered during testing. Analytical data regarding contaminant concentrations within the various fractions, as well as percent solids, O&G, water, etc., were used in conjunction with measurements recorded during the demonstration. Since material holdup within the system could distort the individual material balances obtained for each run (batch), the mass balances calculated within this report evaluate overall performance during the five runs cumulatively. Cumulative balances comparing total materials (including and excluding triethylamine) entering and exiting the B.E.S.T.® system were also performed. Table C-3 summarizes all mass balance results.

Table C-3. Mass Balance Summaries, Percent^a

Sample	Solids	PCBs	PAHs	O&G	Water	Triethylamine	Total Materials	Feed and Product Materials ^b
Sediment A	89	95	115	222	125	87	99.3	108
Sediment B	108	112	126	119	116	82	99.6	114

^a The project objectives for all mass balances were closures between 80 and 130 percent.

^b The vendor claim for this mass balance was closure between 85 percent and 115 percent for feed and product materials.

C.4.1 Solids Balance

Solids balances were performed during the demonstration by comparing the amount of solids entering the system as part of the feed sediment to the process solids recovered. Solids balance results are consistent with demonstration test objectives that closures of between 80 and 130 percent could be obtained for solids treated within the B.E.S.T.[®] system. The mass balances for solids are presented in Table C-4.

Table C-4. Solids Mass Balances

	Sediment A	Sediment B
Solids Input, lbs	474	285
Solids Output, lbs	420	306
Solids Recovery, percent	89	108

C.4.2 PCB Balance

Closures of 95 and 112 percent were obtained for PCBs during the treatment of Sediments A and B, respectively. The amount of PCBs entering the system was calculated by multiplying the analytically determined value for PCB concentrations present within the feed by the weight of the feed entering the system. This value was then compared with the cumulative amount of PCBs deposited in the various system products, particularly the oil product. The PCB balance results are consistent with the demonstration test objectives of closures between 80 and 130 percent. Mass balances for PCBs are presented in Table C-5.

Table C-5. PCB Mass Balances

	Sediment A	Sediment B
PCB Input, lbs	0.00469	0.146
PCB Output, lbs	0.00444	0.163
PCB Recovery, percent	95	112

C.4.3 PAH Balance

Like PCBs, all of the PAHs entered in the feed sediment, while the majority exited in the product oil. Closures of 115 and 126 percent were obtained for PAHs during the treatment of Sediments A and B, respectively. The PAH balance results are consistent with the demonstration test objectives of closures between 80 and 130 percent. Mass balances for PAHs are presented in Table C-6.

Table C-6. PAH Mass Balances

	Sediment A	Sediment B
PAH Input, lbs	0.245	25
PAH Output, lbs	0.283	31
PAH Recovery, percent	115	126

C.4.4 O&G Balance

Closures of 222 and 119 percent were obtained for O&G during the treatment of Sediments A and B, respectively. The amount of O&G entering the system was calculated by multiplying the analytically determined value for the concentration of O&G present within the feed by the weight of the feed entering the system. Values for O&G exiting the system were determined using analytical data regarding O&G concentrations within the oil product. The O&G mass balance closure achieved for Sediment B met the demonstration objective of closure between 80 and 130 percent. The elevated recovery obtained for Sediment A can in part be attributed to inaccuracies in the analytical values achieved for O&G concentrations associated with the low oil content of the sediment entering the system. The determination of the mass of O&G in the Sediment A product oil and solvent mixture was also difficult because of the high solvent fraction of this mixture. In addition, O&G in feed sediments were analytically determined by extraction with methylene chloride, while the pilot unit uses triethylamine as its extraction solvent. The mass balances for O&G are presented in Table C-7.

Table C-7. O&G Mass Balances

	Sediment A	Sediment B
O&G Input, lbs	3.48	67.3
O&G Output, lbs	7.71	80.0
O&G Recovery, percent	222	119

C.4.5 Water Balance

Water balances were performed during the demonstration by comparing the amount of process water entering the B.E.S.T.® system to the mass of product water exiting the system. Although the majority of the process water enters the system as part of the feed, a portion enters the B.E.S.T.® system in the extractor/dryer vessel. Closures of 125 percent and 116 percent were obtained for testing performed on Sediments A and B, respectively. The water balance results are consistent with the demonstration test objectives of closures between 80 and 130 percent. The water balances are shown in Table C-8.

Table C-8. Water Mass Balances

	Sediment A	Sediment B
Water Input, lbs	555	767
Water Output, lbs	692	888
Water Recovery, percent	125	116

C.4.6 Solvent (Triethylamine) Balance

Triethylamine is used as the extraction solvent in the B.E.S.T.® system. The used triethylamine is recovered and reused without exiting the system, although small amounts of triethylamine remain in the treated solids, water product, and oil product. Solvent mass balance closures of 87 percent and 82 percent were obtained for Sediments A and B, respectively. The solvent balance results are consistent with the demonstration test objectives of closures between 80 and 130 percent. Mass balances for triethylamine are presented in Table C-9.

Table C-9. Triethylamine Mass Balances

	Sediment A	Sediment B
Triethylamine Input, lbs	751	891
Triethylamine Output, lbs	652	727
Triethylamine Recovery, percent	87	82

C.4.7 Total Materials Balance

Mass balances for all materials entering and exiting the process were also calculated. Closures of 99.3 percent and 99.6 percent were obtained for Sediment A and Sediment B, respectively. These closures are very good and show that even though individual balances may vary because of the considerable number of analyses involved, no significant amount of material is lost for either Sediment A or Sediment B. The mass balances for the total materials are presented in Table C-10.

Table C-10. Total Materials Mass Balances

	Sediment A	Sediment B
Total Materials Input, lbs	1,784	2,010
Total Materials Output, lbs	1,771	2,002
Total Materials Recovery, percent	99.3	99.6

C.4.8 Feed and Product Materials Balance

Mass balances for all feed and product materials (sediment, water, steam, and sodium hydroxide feed streams; solid, water, and oil products) entering and exiting the process were also calculated. Closures of 108 percent and 114 percent were obtained for Sediment A and Sediment B, respectively. These closures comply with the developer's claim that the mass balance of feed material into the pilot unit versus total products (solids plus water plus oil) out will be in the range of 85 to 115 percent. The mass balances for the feed and product material are presented in Table C-11.

Table C-11. Feed and Product Materials Mass Balances

	Sediment A	Sediment B
Feed Materials Input, lbs	1033	1119
Product Materials Output, lbs	1119	1274
Recovery, percent	108	114

C.5 Leaching Characteristics

The metals portion of the TCLP was performed on both the untreated sediment and the treated solids. As stated in Section 1 of this report, the treated solids and untreated sediment both passed the TCLP for metals, so no significant conclusions can be drawn from data regarding the effects of the B.E.S.T.® process in the treatment of metals.

C.6 PAH and PCB Concentrations in the Product Water and Product Oil

Table C-12 summarizes the PAH and PCB concentrations measured in the product water generated during each of the three optimum runs for each test sediment. Averages of the optimum runs for each sediment are also presented. Table C-13 summarizes the PAH and PCB concentrations measured in the oil produced from the treatment of Sediment B. A total of five aliquots (field replicates) of product oil were collected following triethylamine removal in the solvent evaporator at the end of the fifth and final run. This "oil polishing" distillation procedure was not conducted for Sediment A because of the small amount of oil present in Sediment A.

C.7 Air Emissions

During the demonstration, the ambient air was monitored for ionizable organic vapors using an photoionization detector (PID). The ambient air was monitored on a daily basis 5. meters upwind and downwind from the treatment unit. Particular emphasis was placed on ambient monitoring for volatile emissions attributed to the solvent employed by RCC. The maximum limit for organic vapor concentration in the ambient air was 10 ppm above background levels; none of the measurements taken during the demonstration test exceeded this limit.

Vent gases were filtered by primary and secondary activated carbon canisters and the triethylamine concentration in the air between the two carbon canisters was monitored daily with reaction tubes. The maximum limit for the triethylamine concentration in the air between the two carbon canisters was 3.5 ppm. This limit was exceeded twice during the demonstration test (15 ppm and 30 ppm). In each instance, the primary carbon canister was replaced immediately and the triethylamine concentration returned to below 3.5 ppm. Vent gas triethylamine emissions were not measured at over 0.2 ppm at any time during the demonstration.

C.8 Triethylamine Biodegradation Testing on Treated Solids

Triethylamine biodegradation testing on the treated solids was added to the Demonstration Plan because it was indirectly related to the B.E.S.T.[®] process. Biodegradation was not a critical parameter in the B.E.S.T.[®] SITE demonstration. RCC, the developer, has referenced a U.S. Environmental Protection Agency (EPA) report (EPA-600/2-82-001a) that states that 200 ppm of triethylamine in water was completely degraded in 11 hours by *Aerobacter*, a common soil bacteria. The use of this reference implies that triethylamine may biodegrade in the treated solids. Biodegradation testing was thus intended to indicate whether triethylamine would degrade in the treated solids produced during the SITE demonstration.

Table C-12. PAH and PCB Concentrations in the Product Water

Parameter	Run Numbers					Average of Optimum Runs
	1	2	3	4	5	
Sediment A						
Total PAHs, µg/L	<10	<10	<10	<10	<10	<10
Total PCBs, µg/L	<3	<3	<3	<3	<3	<3
Sediment B						
Total PAHs, µg/L	<10	<10	<10	<10	<10	<10
Total PCBs, µg/L	<10	<1	<1	<1	<1	<1

Table C-13. PAH and PCB Concentrations in the Sediment B Product Oil

Parameter	Aliquot Number ^a					Average
	1	2	3	4	5	
Total PAHs, mg/kg	498,000	438,000	299,000	297,000	436,000	394,000
Total PCBs, mg/kg	2,030	1,750	2,520	2,150	2,180	2,130

^a The aliquots 1 through 5 were collected incrementally as the product oil in the solvent evaporator tank was drained by a hose into a drum.

A very limited biodegradation study was conducted by mixing equal portions of viable potting soil and treated product solid samples collected from three of the demonstration test runs (two Sediment A samples and one Sediment B sample). For each of the three sediment samples, two sets of 12 test vials were prepared; the first set contained unaltered mixtures and the second "control" set contained the same homogeneous mixture spiked with mercuric chloride.

The samples were then stored away from light at room temperature as test sample/control sample pairs. Each pair was analyzed at four separate time intervals.

Table C-14 summarizes the biodegradation test data. The results of the biodegradation study are quite variable but they do not appear to provide any evidence that triethylamine present at 25 to 100 ppm is biodegraded in this soil within 2 months of application.

C.9 Particle Size Distribution

Table C-15 presents particle size distribution data for the untreated solids (by dry sieve testing). The particle size analyses demonstrate the ability of the B.E.S.T.® system to treat materials containing a large fraction of fine particles.

Table C-14. Triethylamine Biodegradability in Treated Solids

Sample	Time Interval Concentrations, mg/kg dry weight ^a			
	Day 0	Day 14	Day 28	Day 56
Sediment A, Run 1				
Test Cell	85.8	85.5	55.0	66.9
Control Cell	73.6	92.3	68.9	57.0
Sediment A, Run 4				
Test Cell	42.4 ^b	53.1	65.0	64.7
Control Cell	30.4 ^b	50.4	70.9	71.4
Sediment B, Run 4				
Test Cell	147	140	148	152
Control Cell	146	155	146	158

a All concentrations are the average of three replicate runs, one of which was analyzed in duplicate.

b Duplicate analysis was not performed on any of the three replicate run samples.

Table C-15. Particle Size Analysis Results

Sample	Percent of Total				
	> 4.75 mm ^a	4.75-2.00 mm ^b	2.00-425 μ m ^c	425- 75 μ m ^d	< 75 μ m ^e
Sediment A					
Feed ^f	0.00	4.60	27.55	40.16	27.69
Treated Solids ^g	0.31	3.86	14.60	49.87	31.36
Sediment B					
Feed ^f	0.00	0.10	4.25	57.20	38.45
Treated Solids ^g	2.38	12.01	60.01	23.83	1.78

a Retained by No. 4 sieve

b Retained by No. 10 sieve

c Retained by No. 40 sieve

d Retained by No. 200 sieve

e Passes No. 200 sieve

f Wet sieve

g Dry sieve

Appendix D

Case Studies

D.1 Massena, New York Pilot-Scale Testing

Pilot-scale tests were conducted in September and October of 1991 in Massena, New York to determine the ability of Resources Conservation Company's (RCC's) Basic Extractive Sludge Treatment (B.E.S.T.®) solvent extraction system to treat six wastes from an aluminum manufacturing facility. Three of the wastes were sludges taken from three lagoons, including a soluble oil lagoon and a sanitary lagoon. The other three wastes were soils, two of which were taken from a waste lubricating oil landfill and a oily waste landfill.

Polychlorinated biphenyls (PCBs) were the target contaminants in all six wastes. Treatment results for the six wastes are shown in Table D-1. The concentrations of PCBs initially present in the wastes ranged from 5 mg/kg to 800 mg/kg, while the treated solids contained between 0.2 mg/kg and 1.0 mg/kg of PCBs. The objective of these tests was to determine whether the B.E.S.T.® process was capable of reducing the PCB concentrations in the soils and sludges to less than 2.0 mg/kg. This goal was achieved for all six wastes.

D.2 Pilot-Scale Testing of Wastes from Wood Treating Facilities

In June 1991, the pilot-scale B.E.S.T.® solvent extraction unit was used to conduct treatability studies on contaminated soil from two wood treating facilities. The soils were transported from the two facilities to the test location in Vicksburg, Mississippi.

The treatability tests conducted on the wood treating wastes were sponsored by the U.S. Environmental Protection Agency (EPA). The objective of these tests was to determine the Best Demonstrated Available Technology (BDAT) standard for contaminated soil and debris. This standard was successfully established.

Polynuclear aromatic hydrocarbons (PAHs) were the target contaminants in these treatability tests. The soil from one of the wood treating facilities contained 10,900 mg/kg PAHs; the resulting treated solids contained 109 mg/kg. This represents a 99 percent reduction in PAHs. The soil from the other wood treating facility contained 14,000 mg/kg of PAHs. Following B.E.S.T.®

Table D-1. Treatment of Aluminum Manufacturing Soils and Sludges

Waste Origin	Initial PCB Concentration	Final PCB Concentration	Removal of PCBs, percent
Soluble Oil Lagoon	530 mg/kg	0.7 mg/kg	99.9
Sanitary Lagoon	137 mg/kg	0.6 mg/kg	99.6
60 Acre Lagoon	480 mg/kg	1.0 mg/kg	99.8
Waste Lubricating Oil Landfill	800 mg/kg	1.0 mg/kg	99.9
Oily Waste Landfill	13 mg/kg	0.3 mg/kg	97.7
Dennison Crossroads	5 mg/kg	0.2 mg/kg	96.0

solvent extraction, the treated solids contained 8.2 mg/kg PAHs. This represents a 99.9 percent reduction in PAHs.

D.3 Pilot-Scale Testing of Waste from Machining Operations

In December 1989, the B.E.S.T.® pilot-scale unit was used to conduct a treatability study in Greenville, Ohio. The soil at this site became contaminated with PCBs as a result of the disposal of lubricants from machining operations. B.E.S.T.® solvent extraction reduced the PCB concentration in the soil from 130 mg/kg to 2.5 mg/kg in the treated solids, a reduction of 98.1 percent. This treatability test easily met its objectives of producing treated solids containing less than 10 mg/kg PCBs.

D.4 Pilot-Scale Testing of Petroleum Refining Sludge

The B.E.S.T.® pilot-scale solvent extraction unit was employed in February 1989 for a treatability test conducted in Baton Rouge, Louisiana. The objective of this treatability test was to establish BDAT standards for K048-K052 wastes. These standards are partially based on the performance of the B.E.S.T.® unit during this pilot-scale test. The waste treated was a sludge containing PAHs and oil and grease (O&G) from petroleum refining operations.

The petroleum refining sludge was initially 26 percent O&G. The treated solids generated by the B.E.S.T.® solvent extraction system contained 0.09 percent O&G and 11.6 mg/kg PAHs.

D.5 Full-Scale Treatment of Oily Sludges

RCC's prototype full-scale B.E.S.T.® solvent extraction system was employed in the treatment of oily sludge at the General Refining site in Garden City, Georgia. This oily sludge was generated during waste oil reclamation and re-refining activities and was disposed of in unlined lagoons. RCC mobilized the full-scale B.E.S.T.® unit and installed it at the General Refining site in mid-1986. The system was tested and modified, then employed in the treatment of approximately 3,700 tons of oily sludges. An extensive 24-hour sampling and monitoring program was conducted during the last week of treatment, which was concluded in March 1987 [1].

The 24-hour test was conducted by RCC with the assistance of the EPA Region X Environmental Services

Division and Region IV Emergency Response and Control Branch. The primary objective of this test was to determine the B.E.S.T.® system's ability to separate the feed components and isolate them into specific product streams. The feed contained PCBs, metals (primarily lead), volatile organics, and semivolatile organics [1].

Samples were collected from the feed stream, product oil, product solids, aqueous product (before and after the water treatment system), blowdown sludge from the water treatment system, process air emissions, and recycled solvent. The organics (PCBs, volatiles, and semivolatiles) from the feed were concentrated in the oil fraction, although minimal amounts of organics were present in the solid and aqueous products. The metals from the feed were primarily concentrated in the solid product, but the concentration of lead in the oil product was also significant. The low concentrations of metals in the aqueous phase were further reduced in the water treatment system [1].

After metals removal, the aqueous product was suitable for discharge into an industrial wastewater treatment facility. TCLP results for lead in the solids product ranged from 4.0 to 12 mg/L, while the regulatory level is 5 mg/L. Because the lead was only marginally leachable and the other metals were present in stable forms that resisted leaching, the test report states that the solids are potentially eligible for land disposal or delisting [1]. The oil product was sold as fuel to a fuel blender.

The B.E.S.T.® solvent extraction system used during this project is a prototype and is the only full-scale unit currently available. This prototype system is capable of treating up to 100 tons of contaminated sludge per day (it is not applicable to contaminated soils). Forty tons of sludge were treated during the 24-hour testing period. The average solvent to feed ratio during this period was 4 to 1. Because the system recycles the solvent, only 16 pounds of solvent were consumed per ton of sludge treated. Furthermore, RCC estimates the system can be modified such that it will only consume 2.5 pounds of solvent per ton of sludge treated [1].

D.6 Reference

1. U.S. Environmental Protection Agency. Evaluation of the B.E.S.T.® Solvent Extraction Sludge Treatment Technology Twenty-Four Hour Test. EPA/600/2-88/051, August 1988.

