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Superfund Innovative Technology Evaluation Program Evaluation of Soil Amendment Technologies at the Crooksville/Roseville Pottery Area of Concern Rocky Mountain Remediation Services Envirobond^{TM} Process

Innovative Technology Evaluation Report

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

Notice

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Foreword

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

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

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

Abstract

Rocky Mountain Remediation Services, L.L.C. (RMRS), of Golden, Colorado, has developed Envirobond™ to treat soil contaminated with metals. RMRS claims that Envirobond™ forms metal complexes that immobilize toxic metals, thereby reducing the risk to human health and the environment.

The Superfund Innovative Technology Evaluation (SITE) Program evaluated an *in situ* application of the technology during a demonstration at two lead contamination sites in Roseville, Ohio, in September 1998. For the demonstration, Envirobond™ was applied to 10 experimental units at a trailer park and one experimental unit at an inactive pottery factory.

Primary objective 1 (P1) was to evaluate whether Envirobond™ can treat soil contaminated with lead to meet the Resource Conservation and Recovery Act (RCRA)/Hazardous and Solid Waste Amendments (HSWA) alternative universal treatment standards (UTS) for land disposal of soils contaminated with lead. The alternative UTS for soil contaminated with lead is determined from the results of the toxicity characteristic leaching procedure (TCLP). The alternative UTS is met if the concentration of lead in the TCLP extract is no higher than one of the following: (1) 7.5 milligrams per liter (mg/L), or (2) 10 percent of the lead concentration in the TCLP extract from the untreated soil. Contaminated soils with TCLP lead concentrations below the alternative UTS meet the RCRA land disposal restrictions (LDR), and thus are eligible for disposal in a land-based RCRA hazardous waste disposal unit. The alternative UTS is defined further under Title 40 of the Code of Federal Regulations (CFR), Chapter I, part 268.49 (40 CFR 268.49). To meet that objective, soil samples were collected before and after the application of Envirobond™. The untreated and treated soil samples were analyzed for TCLP lead concentrations to evaluate whether the technology met objective P1. Analysis of the data demonstrated Envirobond™ reduced the mean TCLP lead concentration at the inactive pottery factory from 382 mg/L to 1.4 mg/L, a reduction of more than 99 percent. Therefore, the treated soil meets the alternative UTS for soil at the inactive pottery factory. Data from the trailer park were not used to evaluate P1 because TCLP lead concentrations in all treated and untreated soil samples from this location were either at or slightly higher than the detection limit of 0.05 mg/L.

Primary objective 2 (P2) was to evaluate whether Envirobond™ could decrease the soil lead bioaccessibility by 25 percent or more, as defined by the Solubility/Bioaccessibility Research Consortium's (SBRC) Simplified In-Vitro Test Method for Determining Soil Lead and Arsenic Bioaccessibility (simplified in vitro method [SIVM]). However, EPA Lead Sites Workgroup (LSW) and Technical Review Workgroup for lead (TRW) at this time, do not endorse an in-vitro test for determining soil lead bioaccessibility (Interstate Technology and Regulatory Cooperation [ITRC] 1997). To meet objective P2, soil samples were collected before and after the application of Envirobond™. The soil samples were analyzed for soil lead bioaccessibility to evaluate whether the technology met objective P2. Analysis of the data demonstrates that Envirobond™ reduced the soil lead bioaccessibility by approximately 12.1 percent, which is less than the project goal of at least a 25 percent reduction in soil lead bioaccessibility. However, it was recognized early on that meeting this goal would be difficult because the SIVM test procedure used in the demonstration involves a highly acidic sample digestion process, which may be revised in the future, because it may be exceeding the acid concentrations that would be expected in a human stomach.

An economic analysis examined 12 cost categories for a scenario in which the Envirobond™ process was applied at full scale to treat 807 cubic yards lead contaminated soil at a 1-acre site within the CRPAC. The cost was estimated to be $41.16 per cubic yard of treated soil. However, the cost for using this technology is site-specific.

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Acronyms, Abbreviations, and Symbols

ACGIH TLV	American Conference of Governmental Industrial Hygiene Threshold Limit Value
ASTM	American Society for Testing and Materials
ARAR	Applicable or relevant and appropriate requirements
BS	Blank spike
$CaCO_3$	Calcium carbonate
CFR	*Code of Federal Regulations*
CEC	Cation exchange capacity
CRPAC	Crooksville/Roseville Pottery Area of Concern
cm^3	Cubic centimeter
DQO	Data quality objective
DUP	Duplicate
Eh	Oxidation reduction potential
EPA	U.S. Environmental Protection Agency
EP-TOX	Extraction procedure toxicity test
GI	U.S. Environmental Protection Agency Regional Geographic Initiative
HSWA	Hazardous and Solid Waste Act
ICP-AES	Inductively coupled plasma-atomic emission spectrometry
ITER	Innovative technology evaluation report
LCS	Laboratory control samples
LCSD	Laboratory control sample duplicates
MS	Matrix spike
MSD	Matrix spike duplicate
MEP	Multiple extraction procedure
Fg/dL	Micrograms per deciliter
Meq/g	Milliequivalents per gram
mg/kg	Milligram per kilogram
mg/L	Milligram per liter
mV	Millivolt
NAAQS	National Ambient Air Quality Standard
NCP	National Oil and Hazardous Substances Pollution Contingency Plan

Acronyms, Abbreviations, and Symbols (continued)

NIOSH REL	National Institute for Occupational Safety and Health recommended exposure limit
NPDES	National Pollutant Discharge Elimination System
NRMRL	National Risk Management Research Laboratory
OEPA	Ohio Environmental Protection Agency
ORD	Office of Research and Development
OSHA	Occupation Safety and Health Administration
OSHA PEL	Occupation Safety and Health Administration permissible exposure limit
OSWER	Office of Solid Waste and Emergency Response
PBET	Physiologically based extraction test
%R	Percent recovery
POTW	Publicly owned treatment works
PPE	Personal protective equipment
PRDL	Project-required detection limits
PRP	Potentially responsible party
QAPP	Quality assurance project plan
QA/QC	Quality assurance and quality control
RCRA	Resource Conservation and Recovery Act
RMRS	Rocky Mountain Remediation Services, L.L.C.
RPD	Relative percent difference
RPM	Remedial Project Manager
SARA	Superfund Amendments and Reauthorization Act
SBRC	Solubility/Bioavailability Research Consortium
SITE	Superfund Innovative Technology Evaluation
SIVM	Simplified in-vitro method
SPLP	Synthetic precipitation leaching procedure
SVOC	Semivolatile organic compound
TCLP	Toxicity Characteristic Leaching Procedure
TER	Technology Evaluation Report
μg/kg	Microgram per kilogram
μg/L	Microgram per liter
UTS	Universal treatment standard
VOC	Volatile organic compound
yd^3	cubic yard

Table of Conversion Factors			
	To Convert from	to	Multiply by
Length:	inch	centimeter	2.54
	foot	meter	0.305
	mile	kilometer	1.61
Area:	square foot	square meter	0.0929
	acre	square meter	4,047
Volume:	gallon	liter	3.78
	cubic foot	cubic meter	0.0283
	cubic foot	gallon	7.48
	cubic foot	cubic centimeter	28,317
	cubic yard	cubic meter	1.3
Mass:	pound	kilogram	0.454
	ton	kilogram	908
Temperature:	(° Fahrenheit - 32)	° Celsius	0.556

Acknowledgments

This report was prepared for the U.S. Environmental Protection Agency's Office of Research and Development, Superfund Innovative Technology Evaluation (SITE) Program by Tetra Tech EM Inc. under the direction and coordination of Mr. Edwin Barth, project manager for the SITE Program at the National Risk Management Research Laboratory, Cincinnati, Ohio.

Executive Summary

Rocky Mountain Remediation Services, L.L.C. (RMRS) has developed Envirobond™ to reduce the mobility of metals in soils. During September 1998, an *in situ* application of the technology was demonstrated under the U.S. Environmental Protection Agency's (EPA) Superfund Innovative Technology Evaluation (SITE) Program on soil contaminated with lead at two sites in Roseville, Ohio.

The purpose of this innovative technology evaluation report (ITER) is to present information that will assist Superfund decision makers in evaluating Envirobond™ for application at a particular hazardous waste site. This report provides an introduction to the SITE program and Envirobond™ and discusses the demonstration objectives and activities (Section 1); evaluates the technology's effectiveness (Section 2); analyzes key factors related to application of the technology (Section 3); analyzes the costs of using the technology to reduce the mobility of lead in soil, as well as the soil lead bioaccessibility (Section 4); summarizes the technology's current status (Section 5); and presents a list of references.

This executive summary briefly summarizes the information discussed in the ITER and evaluates the technology with respect to the nine criteria applied in Superfund feasibility studies.

Technology Description

RMRS claims that the Envirobond™ process can bind with metals in contaminated soils, sludges, mine tailings, process residuals, and other solid wastes. RMRS further claims that the Envirobond™ process converts each metal contaminant from its leachable form to a stable, nonhazardous metallic complex. The Envirobond™ process is a mixture of ligands that act as chelating agents. In the chelation reaction, coordinate bonds attach the metal ion to at least two ligand nonmetal ions to form a heterocyclic ring. By effectively binding the metals, RMRS claims that the Envirobond™ process reduces the waste stream's Toxicity Characteristic Leaching Procedure (TCLP) test results to less than the regulated levels, subsequently reducing the risks posed to human health and the environment.

Overview of the SITE Demonstration

The SITE demonstration of Envirobond™ was conducted in September 1998 at two sites in Roseville, Ohio: an inactive pottery factory and a trailer park. Both sites are located in the Crooksville/Roseville Pottery Area of Concern (CRPAC). Historically, the CRPAC was a major pottery manufacturing area. Lead was used in the glazing process of the pottery finishing process; as a result, has contaminated the upper portion of the soil layer. Soil samples collected by the Ohio Environmental Protection Agency (OEPA) in 1997 indicated that elevated levels of lead were present in the CRPAC. Waste disposal practices and residue from the operation of the kiln at the inactive pottery factory may have contributed to contamination of the soil adjacent to the factory. Waste from several pottery factories in the CRPAC was used as fill material in the vicinity of the trailer park. The fill material may be the source of the lead contamination of the soil at the trailer park.

For the SITE demonstration, soil samples were collected before and after application of Envirobond™ to evaluate whether the technology could achieve the treatment goals of the demonstration project. The project had two primary objectives and four secondary objectives.

The primary objectives of the SITE demonstration were

- Primary Objective 1 (P1) - Evaluate whether Envirobond™ can treat soils contaminated with lead to meet the Resource Conservation and Recovery Act (RCRA)/Hazardous and Solid Waste Amendments (HSWA) alternative universal treatment standard (UTS) for land disposal of soils contaminated with lead that meet the definition of a hazardous waste. The alternative UTS for lead in such soil is determined from the results of the toxicity characteristic leaching procedure (TCLP). The alternative UTS for lead is met if the concentration of lead in the TCLP extract is no higher than one of the following: (1) 7.5 milligrams per liter (mg/L), or (2) 10 percent of the lead concentration in the TCLP extract from the untreated soil. The alternative UTS is defined further in Title 40 of the Code of Federal Regulations (CFR), Chapter I, part 268.49 (40 CFR 268.49).

- Primary Objective 2 (P2) - Evaluate whether Envirobond™ can decrease the soil lead bioaccessibility by 25 percent or more, as defined by the Solubility/Bioaccessibility Research Consortium's (SBRC) In-Vitro Method for Determination of Lead and Arsenic Bioaccessibility (simplified in-vitro method [SIVM]) (Note: the EPA Lead Sites Workgroup (LSW) and Technical Review Workgroup for lead (TRW) at this time do not endorse an in vitro test for determining soil lead bioaccessibility [ITRC 1997]).

The secondary objectives of the demonstration were

- Secondary Objective 1 (S1) - Evaluate the long-term chemical stability of the treated soil.
- Secondary Objective 2 (S2) - Demonstrate that the application of Envirobond™ did not increase the public health risk of exposure to lead.
- Secondary Objective 3 (S3) - Document baseline geophysical and chemical conditions in the soil before the application of Envirobond™.
- Secondary Objective 4 (S4) - Document the operating and design parameters of Envirobond™.

SITE Demonstration Results

Summarized below are the significant results of the SITE demonstration:

- Envirobond™ reduced the mean TCLP lead concentration from 382 mg/L to 1.4 mg/L at the inactive pottery factory, a reduction of more than 99 percent. Therefore, the treated soil meets the alternative UTS for soils contaminated with lead, as specified at CFR 268.49. Data from the trailer park were not used to evaluate P1 because TCLP lead concentrations in all treated and untreated soil samples from this location were either at or slightly higher than the detection limit of 0.05 mg/L.
- Analysis of the data generated by application of the SIVM demonstrated that Envirobond™ reduced the soil lead bioaccessibility by approximately 12.1 percent. However, it was recognized early on that meeting this goal would be difficult because the SIVM test procedure used in the demonstration involves a highly acidic sample digestion process, which may be revised in the future, because it may be exceeding the acid concentrations that would be expected in a human stomach.
- Soil treated with Envirobond™ appears to exhibit long-term chemical stability, as indicated by the results of most of the 11 analytical procedures that were conducted to predict the long-term chemical stability of the treated soil. However, the results of some of the analytical procedures suggest that Envirobond™ does not appear to exhibit long-term chemical stability. In summary:

  — Long-term soil chemical stability was indicated for soils treated by Envirobond™ at both test locations, as indicated by the analytical results of the multiple extraction procedure (MEP), the procedure for lead speciation by sequential extraction, the test for cation exchange capacity (CEC), and leachable lead by the simulated precipitation leaching procedure (SPLP). The CEC results are considered to be qualitative, because this test was conducted on only a single sample from each location.

  — Long-term chemical stability was indicated at one site, but not at the other, by the analytical results of procedures for evaluating acid neutralization capacity. The acid neutralization results are considered to be qualitative, because this test was conducted on only a single sample from each location.

  — The analytical results from the lead speciation test by scanning electron microscopy (conducted only on soils from the trailer park) were mixed, in that the silica phosphate phase (low solubility) of lead was increased and some soluble phases of lead were reduced, while other low-solubility phases of lead were also reduced.

  — At both locations, long-term chemical stability was not indicated for soils treated by Envirobond™ by the results of the pH analyses, Eh analyses, separate analyses for total lead by nitric and hydrofluoric acids; total phosphates; and SPLP phosphates (It should be noted that the tests involving two types of total lead analysis were extremely aggressive tests, thus meeting the acceptance criteria established for these tests was not as important as meeting the acceptance criteria of other tests involving long-term chemical stability).
- As the analytical results for the air samples demonstrated, the dust generated during site preparation activities prior to the application of Envirobond™ may exceed the National Ambient Air Quality Program Standard for lead of 1.5 micrograms per cubic meter of air. Therefore, if it is determined that it is necessary to remove the soil or use other techniques that might generate

dust, it is recommended that air monitoring (with real-time devices correlated to actual lead concentrations in the air) be employed; and, if necessary, dust suppression measures also should be employed.

- Based on visual observations during the demonstration, the application of Envirobond™ does not appear to create significant quantities of dust.

- On the basis of information obtained from the SITE demonstration, RMRS, and other sources, an economic analysis examined 12 cost categories for a scenario in which Envirobond™ was applied at full scale to treat 807 cubic yards (yd^3) of soil contaminated with lead at a 1-acre site at CRPAC. The cost estimate assumed that the concentrations of lead in the soil were the same as those encountered during the Roseville demonstration. On the basis of those assumptions, the cost was estimated to be \$41.16 per yd^3 of treated soil, which is a site-specific estimate.

Superfund Feasibility Study Evaluation Criteria for the Envirobond™ Process

Table ES-1 presents an evaluation of Envirobond™ with respect to the nine evaluation criteria used for Superfund feasibility studies that consider remedial alternatives for superfund Sites.

Table ES-1. Evaluation of Envirobond™ by Application of the Nine Criteria for Superfund Feasibility Studies

Criterion		Discussion
1.	Overall Protection of Human Health and the Environment	The technology is expected to significantly lower the leachability of lead from soils as indicated by the TCLP results, thereby reducing the migration of lead to groundwater and the potential for exposure of all receptors to lead; however, the technology did not significantly reduce soil lead bioaccessibility, as determined by the SIVM.
2.	Compliance with Applicable or Relevant and Appropriate Requirements (ARAR)	During the SITE demonstration, Envirobond™ reduced the mean TCLP lead concentration from 382 mg/L to 1.4 mg/L, a reduction of more than 99 percent. Further, the treated TCLP lead concentrations were less than the alternative UTS for lead in soil. Therefore, the treated soil met the land disposal restrictions (LDR) for lead-contaminated soil, as specified in 40 CFR 268.49. However, the technology's ability to comply with existing federal, state, or local ARARs should be determined on a site-specific basis.
3.	Long-term Effectiveness and Permanence	The analytical results of procedures for the multiple extraction procedure (MEP), the procedure for lead speciation by sequential extraction, the test for cation exchange capacity (CEC), and leachable lead by the simulated precipitation leaching procedure (SPLP) suggest long-term chemical stability of the treated soil. The analytical results of a number of other procedures do not suggest long-term chemical stability of the treated soil. Those procedures included pH analyses, Eh analyses, separate analyses for total lead by nitric and hydrofluoric acids; total phosphates; and SPLP phosphates. The results related to long-term effectiveness from the test for lead speciation by scanning electron microscopy and acid neutralization were inconclusive.
4.	Short-term Effectiveness	Short-term effectiveness is high; measures to control dusts and surface runoff controls may be needed at some sites.
5.	Reduction of Toxicity, Mobility, or Volume Through Treatment	The mean TCLP lead concentration was reduced from 382 mg/L to 1.4 mg/L, reducing the mobility of the lead in the soil.
6.	Implementability	The technology is relatively easy to apply. Large areas can be treated using common farm equipment, and small areas can be treated using readily available home gardening tools (sod cutter, tiller, fertilizer sprayer).
7.	Cost	For full-scale application of the technology at a 1-acre site contaminated with lead in the top 6 inches of soil, estimated costs are \$33,220, which is \$41.16 per cubic yard.
8.	Community Acceptance	Community acceptance of Envirobond™ likely will be a site-specific issue.
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1.0 Introduction

This section provides background information about the Superfund Innovative Technology Evaluation (SITE) Program and reports related to it; describes Envirobond™; presents the objectives of the SITE demonstration; and provides information about key contacts.

1.1 Description of SITE Program and Reports

This section provides information about the purpose, history, goals, and implementation of the SITE program, and about reports that document the results of SITE demonstrations.

1.1.1 Purpose, History, Goals, and Implementation of the SITE Program

The primary purpose of the SITE program is to advance the development and demonstration, and thereby establish the commercial availability, of innovative treatment technologies applicable to Superfund and other hazardous waste sites. The SITE program was established by the U.S. Environmental Protection Agency's (EPA) Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) in response to the Superfund Amendments and Reauthorization Act of 1986 (SARA), which recognizes the need for an alternative or innovative treatment technology research and demonstration program. The SITE program is administered by ORD's National Risk Management Research Laboratory (NRMRL) in Cincinnati, Ohio. The overall goal of the SITE program is to carry out a program of research, evaluation, testing, development, and demonstration of alternative or innovative treatment technologies that can be used in response actions to achieve more permanent protection of human health and the environment.

Each SITE demonstration evaluates the performance of a technology in treating a specific waste. The waste characteristics at other sites may differ from the characteristics of those treated during the SITE demonstration. Further, the successful field demonstration of a technology at one site does not necessarily ensure that it will be applicable at other sites. Finally, data from the field demonstration may require extrapolation to estimate (1) the operating ranges under which the technology will perform satisfactorily and (2) the costs associated with application of the technology. Therefore, only limited conclusions can be drawn from a single field demonstration, such as a SITE technology demonstration.

The SITE program consists of four components: (1) the Demonstration Program, (2) the Emerging Technology Program, (3) the Monitoring and Measurement Technologies Program, and (4) the Technology Transfer Program. The SITE demonstration described in this innovative technology evaluation report (ITER) was conducted under the Demonstration Program. The objective of the Demonstration Program is to provide reliable performance and cost data on innovative technologies so that potential users can assess a given technology's suitability for cleanup of a specific site. To produce useful and reliable data, demonstrations are conducted at hazardous waste sites or under conditions that closely simulate actual conditions at waste sites. The program's rigorous quality assurance and quality control (QA/QC) procedures provide for objective and carefully controlled testing of field-ready technologies. Innovative technologies chosen for a SITE demonstration must be pilot- or full-scale applications and must offer some advantage over existing technologies.

Implementation of the SITE program is a significant, ongoing effort that involves OSWER, ORD, various EPA regions, and private business concerns, including technology developers and parties responsible for site remediation. Cooperative agreements between EPA and the innovative technology developer establish responsibilities for conducting the demonstrations and evaluating the technology. The developer typically is responsible for demonstrating the technology at the selected site and is expected to pay any costs of transportation, operation, and removal of related equipment. EPA typically is responsible for project planning, site preparation, provision of technical assistance, sampling and analysis, QA/QC, preparation of reports, dissemination of information, and transportation and disposal of treated waste materials.

1.1.2 Documentation of the Results of SITE Demonstrations

The results of each SITE demonstration are reported in an ITER and a technology evaluation report (TER). The ITER is intended for use by EPA remedial project managers (RPM) and on-scene coordinators, contractors, and others involved in the remediation decision-making process and in the implementation of specific remedial actions. The ITER is designed to aid decision makers in determining whether specific technologies warrant further consideration as options applicable to particular cleanup operations. To encourage the general use of demonstrated technologies, EPA provides information about the applicability of each technology to specific sites and wastes. The

ITER provides information about costs and site-specific characteristics. It also discusses the advantages, disadvantages, and limitations of the technology.

The purpose of the TER is to consolidate all information and records acquired during the demonstration. The TER presents both a narrative and tables and graphs that summarize data. The narrative discusses predemonstration, demonstration, and postdemonstration activities, as well as any deviations from the quality assurance project plan (QAPP) for the demonstration during those activities and the effects of such deviations. The data tables summarize the QA/QC data. EPA does not publish the TER; instead, a copy is retained as a reference by the EPA project manager for use in responding to public inquiries and for recordkeeping purposes.

1.2 Description of Envirobond™

The Envirobond™ process is a combination of a proprietary powder and solution that binds with metals in contaminated soils and other wastes. Rocky Mountain Remediation Services, L.L.C. (RMRS), the developer of the process, claims that the Envirobond™ process effectively prevents metals from leaching and can be used with mechanical compaction to reduce the overall volume of contaminated media by 30 to 50 percent. The Envirobond™ process generates no secondary wastes and involves minimal handling, transportation, and disposal costs.

The Envirobond™ process consists of a mixture of additives containing oxygen, nitrogen, and phosphorous; each additive has an affinity for a specific class of metals. RMRS claims that the Envirobond™ process converts each metal contaminant from its leachable form to an insoluble, stable, nonhazardous metallic complex. The Envirobond™ process is essentially a mixture of ligands that act as chelating agents. In the chelation reaction, coordinate bonds attach the metal ion to at least two ligand nonmetal ions to form a heterocyclic ring. The resulting ring structure is inherently more stable than simpler structures formed in many binding processes. RMRS claims that, by effectively binding the metals, the Envirobond™ process reduces the waste stream's leachable metal concentrations to less than regulated levels, and thereby reduces the risks posed to human health and the environment.

The Envirobond™ process can be deployed as an *in situ* or *ex situ* treatment process. RMRS reports that the Envirobond™ process is capable of achieving processing rates of 20 to 40 tons per hour for *ex situ* treatment and can be used with contaminated media containing as much as 10 percent debris.

1.3 Overview and Objectives of the SITE Demonstration

This section provides information about (1) the site background and location, (2) the objectives of the SITE demonstration, (3) demonstration activities, and (4) long-term monitoring activities.

1.3.1 Site Background

The villages of Crooksville and Roseville, located along the Muskingum and Perry County line in eastern Ohio, are famous for a long history of pottery production. During the 100-year period of pottery manufacturing in those villages, broken and defective (off-specification [off-spec]) pottery was disposed of in several areas. Disposal practices were not monitored or documented clearly. Sampling conducted in the region by the Ohio Environmental Protection Agency (OEPA) in 1997 identified 14 former potteries and pottery disposal sites at which significant lead contamination was present. Results of analysis of the soil samples collected by OEPA in 1997 indicated elevated levels of lead in shallow soils throughout the area (OEPA 1998) identified as the Crooksville/Roseville Pottery Area of Concern (CRPAC). Much of the lead contamination is associated with the disposal of unused glazing materials or of off-spec pottery that was not fired in a kiln.

In 1996, OEPA entered into a cooperative agreement with EPA to conduct an investigation of the CRPAC under a regional geographic initiative (GI). The GI program provides grants for projects that an EPA region, a state, or a locality has identified as high priority and at which the potential for risk reduction is significant. The GI program allows EPA regions to address unique, multimedia regional environmental problems that may pose risks to human health or to the environment, such as the widespread lead contamination found at the CRPAC.

The purpose of the GI of the investigation of the CRPAC was to determine whether the long history of pottery operations there, from the late 1800s through the 1960s, caused any increases over background levels of concentrations of heavy metals in soil, groundwater, surface water, or air. The results of analysis of soil and groundwater samples collected in 1997 indicate elevated levels of lead are present in shallow soils and groundwater throughout the CRPAC (OEPA 1998).

1.3.2 Site Location

OEPA selected four potential demonstration sites in the CRPAC on the basis of the analytical results for samples collected as part of the GI. Before the demonstration was conducted, SITE personnel collected and analyzed soil samples from the potential demonstration sites to determine the extent of the lead contamination at those sites.

On the basis of the analytical results and discussions with representatives of OEPA, two sites in the CRPAC were selected for the SITE demonstration project. One site is a former trailer park in Roseville, Ohio, which is one of many residential areas in the CRPAC that have been affected by the disposal of the pottery waste. The other site, also in Roseville, Ohio, is located in an industrial area, adjacent to an inactive pottery factory. Figure 1-1 shows the locations of the demonstration sites.

1.3.3 SITE Demonstration Objectives

OEPA applied to the SITE program for assistance in evaluating innovative, cost-effective technologies that could be

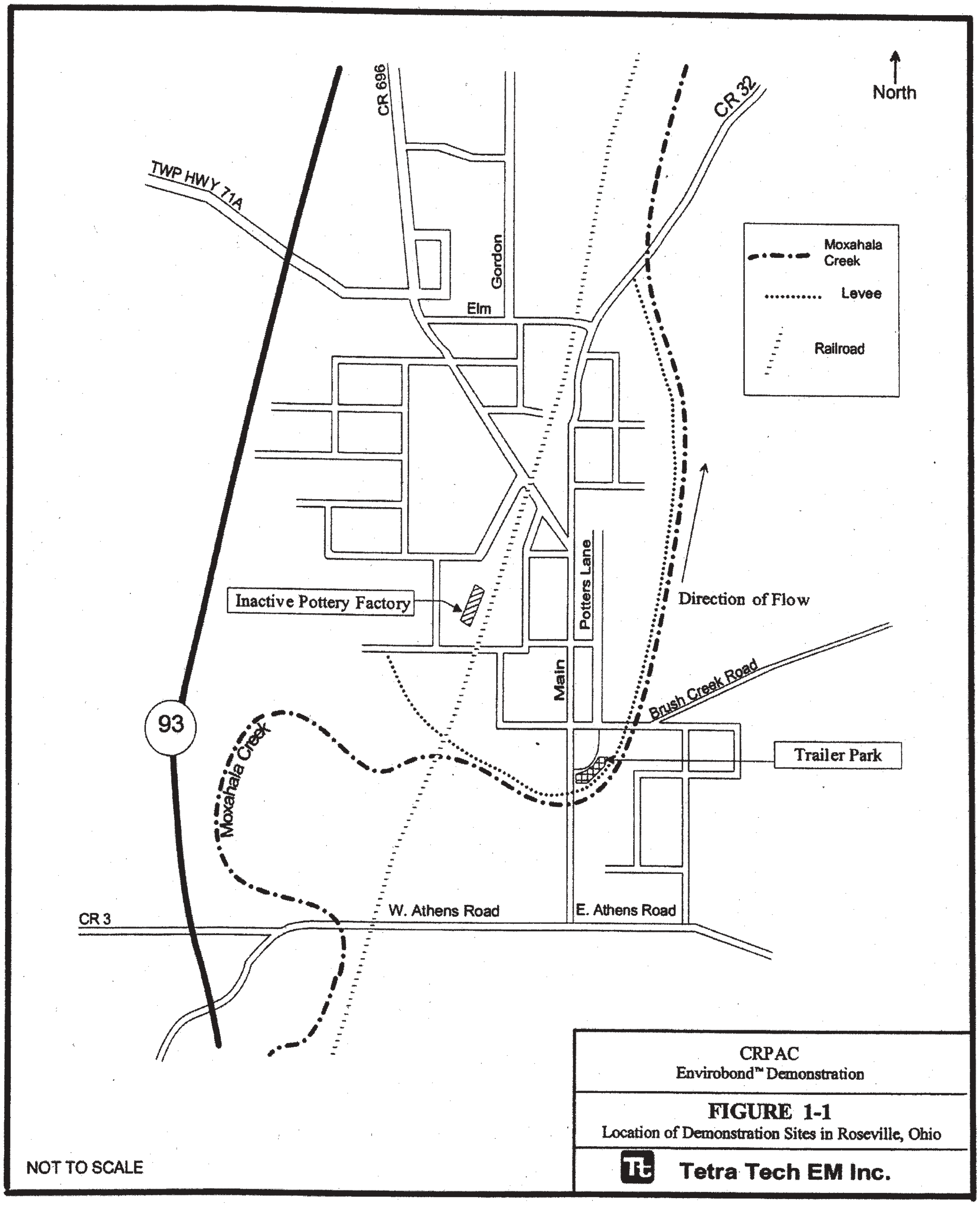

Figure 1-1. Location of demonstration sites in Roseville, Ohio.

applied at the CRPAC. OEPA was considering excavating the soil and stabilizing it with Portland cement; however, the agency also sought to evaluate an innovative technology that could be applied in lieu of soil excavation and that was lower in cost than the cement-based soil stabilization technology. OEPA indicated that children in the CRPAC exhibited higher blood concentrations of lead than children in areas that are not affected by the waste disposal practices of the pottery factories. Therefore, OEPA also was interested in identifying a technology that could reduce the risk of direct exposure to lead in the soil at the CRPAC. To meet OEPA's needs, the SITE program recommended the evaluation of Envirobond™ because it is a technology that can be applied *in situ* with standard construction or farm equipment. EPA refined the objectives of the demonstration project during a meeting with OEPA on March 19, 1998. During and following this meeting, EPA and OEPA established primary and secondary objectives for the SITE demonstration. The objectives were based on EPA's understanding of the technology; information provided by the developers of Envirobond™; the needs identified by OEPA; and the goals of the SITE demonstration program, which include providing potential users of Envirobond™ with technical information to be used in determining whether the technology is applicable to other contaminated sites.

The objectives of the demonstration originally were defined in the EPA-approved QAPP dated November 1998 (Tetra Tech 1998). The two primary objectives are structured to evaluate the ability of the technology to reduce the leachable and bioaccessible concentrations of lead in soils, respectively. The secondary objectives are structured to evaluate the technology's ability to meet other performance goals not considered critical, to document conditions at the site, to document the operating and design parameters of the technology, and to determine the costs of applying the technology.

Primary Objectives

Two primary objectives were developed for the demonstration.

- Primary objective 1 (P1) was to evaluate whether leachable lead in soil can be reduced to concentrations that comply with the alternative UTS for lead in contaminated soil, which are codified at 40 Code of Federal Regulations (CFR) part 268.49 and are included in the land disposal requirements (LDR) set forth under the Resource Conservation and Recovery Act (RCRA)/Hazardous and Solid Waste Amendments (HSWA).

- Primary objective 2 (P2) was to determine whether the portion of total lead in soil that is "bioaccessible," as measured by an experimental method, could be reduced by at least 25 percent. However, it was recognized early on that meeting this goal would be difficult because the SIVM test procedure used in the demonstration involves a highly acidic sample digestion process, which may be revised in the future, because it may be exceeding the acid concentrations that would be expected in a human stomach.

Each of the objectives is described below.

Concentrations of lead in contaminated soils that are the subject of cleanup actions often meet the definition of a hazardous waste under RCRA/HSWA. Sometimes, the goals for such cleanup actions include a requirement that the soil be treated, either *in situ* or *ex situ*, to the point that it is in compliance with the LDRs set forth under RCRA/HSWA. A common reason for including such a treatment goal is to ensure that the lead in treated soil is immobilized sufficiently to make it unlikely that the soil will migrate to groundwater. A treated soil is deemed to be in compliance with the LDRs for lead if the concentration of lead, as measured by a TCLP analysis, is 90 percent lower than the concentration of untreated soil or the treated soil is less than or equal to 7.5 milligrams per liter (mg/L). Objective P1 for this demonstration required that the mean concentration of TCLP lead in the treated soil be 90 percent lower than the concentration in untreated soil or less than or equal to 7.5 mg/L. In addition, the objective required the use of statistical analyses of mean concentrations of TCLP lead, in which the alpha level was set at 0.05.

Bioaccessibility of lead is not normally measured at contaminated sites. The treatment goals for sites at which the soil is contaminated with lead usually are based on the results obtained from lead exposure models that can calculate a maximum total concentration of lead in soil that will not cause blood concentrations of lead in children that exceed the widely accepted threshold level of 10 micrograms per deciliter (Fg/dL). Such models often include a factor that determines the portion of total lead (after ingestion) that is bioavailable. Bioavailability refers to that portion of total soil lead that is absorbed into the bloodstream from the ingestion of the soil (Interstate Technology and Regulatory Cooperation [ITRC] 1997); it is determined through the use of a number of techniques approved by EPA that incorporate the results of in-vivo tests. "Bioaccessibility" of soil lead has been proposed as a term that refers to the results of simpler, in-vitro tests that can be used as indicators of the bioavailability of soil lead. One such test method is the In-Vitro Method for Determination of Lead and Arsenic Bioaccessibility (or simplified in vitro method [SIVM]), which was developed by the Solubility/Bioaccessibility Research Consortium (SBRC) (ITRC 1997). The test simulates digestion of ingested lead in soil, using a combination of chemicals found in the human stomach. Although the EPA Lead Sites Workgroup (LSW) and Technical Review Workgroup (TRW) for lead currently do not endorse an in vitro test for determining soil lead bioavailability (ITRC 1997), such tests, if endorsed in the future, have the potential for use in rapid evaluation of the ability of soil treatment chemicals to reduce the total concentrations of bioavailable lead. The SIVM currently is undergoing validation studies. In previous studies, the test results correlated well with results of analysis by in vivo for soil lead tests based on the Sprague-Dawley rat model and a swine model (ITRC 1997). Primary objective P2 was to evaluate whether Envirobond™ could decrease the bioaccessibility of soil lead (as measured by the SIVM) by 25 percent or more. In addition, the objective required the use of statistical analyses of mean percent lead concentrations, in which the alpha level was set at 0.05.

Secondary (S) Objectives

Secondary objectives were established to collect additional data considered useful, but not critical, to the evaluation of Envirobond™. The secondary objectives of the demonstration were as follows:

- Secondary Objective 1 (S1) - Evaluate the long-term chemical stability of the treated soil.
- Secondary Objective 2 (S2) - Demonstrate that the application of Envirobond™ did not increase the public health risk of exposure to lead.
- Secondary Objective 3 (S3) - Document baseline geophysical and chemical conditions in the soil before the addition of Envirobond™.
- Secondary Objective 4 (S4) - Document operating and design parameters of Envirobond™.

S1 was to determine whether Envirobond™ can enhance the long-term chemical stability of the treated soil. Long-term chemical stability is demonstrated most convincingly through an extended monitoring program. However, the results of such programs may not be available for several years. Therefore, a number of alternative analytical procedures were selected and applied to untreated and treated soils collected from both sites. Those procedures included the multiple extraction procedure (MEP), lead speciation using a scanning electron microscope (SEM), lead speciation with a sequential extraction procedure, oxidation-reduction potential (Eh), pH, cation exchange capacity (CEC), acid neutralization capacity, total lead (as determined by two different methods), leachable lead by the synthetic precipitation leaching procedure (SPLP), total phosphates, and SPLP-leachable phosphates. The evaluation was accomplished by comparing the results of the analytical procedures on soil samples collected from both sites before and after application of Envirobond™. Section 2.3 of this ITER provides additional details about each analytical procedure and the criteria applied in interpreting the results obtained.

S2 was to determine whether the dust generated during the application of Envirobond™ may increase risks to the public health posed by inhalation of lead during full-scale implementation. The evaluation was accomplished by analyzing residuals from air samples that were drawn through filters during those demonstration activities that could create dust and comparing the analytical results with the National Ambient Air Quality Standard (NAAQS) for lead.

S3 was to evaluate baseline geophysical and chemical properties of the soil at both sites. The objective was accomplished by classifying soil samples from both sites and analyzing them for volatile organic compounds (VOC), semivolatile organic compounds (SVOC), oil and grease, and humic and fulvic acids.

S4 was to estimate the costs associated with the use of Envirobond™. The cost estimates were based on observations made and data obtained during and after the demonstration, as well as data provided by RMRS.

1.3.4 Demonstration Activities

Personnel of the SITE program evaluated the objectives of the demonstration by collecting and analyzing surficial soil samples before and after Envirobond™ was applied. Soil samples collected from the inactive pottery factory and the trailer park were used in determining success in accomplishing objective P1. In the case of P2, only soil samples collected from the trailer park were used. In general, five types of data were obtained: (1) TCLP lead concentrations in untreated and treated soils; (2) bioaccessibility levels of lead in untreated and treated soils; (3) various levels of parameters for evaluating the long-term chemical stability of untreated and treated soils; (4) concentrations of lead in air during sampling and treatment activities; and (5) levels of baseline geophysical and chemical parameters in untreated soils. The sampling program was designed specifically to support the demonstration objectives presented in Section 1.3.3. Section 2.0 of this ITER discusses the results of the evaluation.

1.3.5 Long-term Monitoring

A long-term monitoring program was established; under that program, additional samples of soil are to be collected quarterly and analyzed for soil lead bioaccessibility, TCLP lead, concentrations of SPLP lead, and concentrations of lead in groundwater. Water samples will be collected quarterly from lysimeters installed in experimental units at both sites and analyzed for lead. Samples of grass will be collected from experimental units at the trailer park. Information obtained through the long-term monitoring effort will be presented in reports to be issued periodically as the long-term monitoring program proceeds.

1.4 Key Contacts

Additional information about the SITE program, Envirobond™, RMRS, OEPA, and the analytical laboratories is available from the following sources:

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2.0 Technology Effectiveness Analysis

This section addresses the effectiveness of Envirobond™ as observed during the demonstration of the technology at the selected sites at the CRPAC. Section 2.1 describes the predemonstration activities that lead to the selection of the two locations for the demonstration; Section 2.2 presents the activities conducted during the demonstration, including the establishment of experimental units at each demonstration site, and the collection of untreated and treated soil samples; Section 2.3 describes the laboratory analytical and statistical methods used to evaluate demonstration objectives; Section 2.4 presents results of the demonstration; and Section 2.5 provides a summary of results obtained from the analysis of quality control samples that were collected during the demonstration.

2.1 Predemonstration Activities

Predemonstration activities included preliminary sampling at four candidate locations, followed by selection of two demonstrations sites. In March 1998, site personnel collected soil samples from four locations that had been identified by OEPA as potential demonstration sites. Three of the locations were at pottery factories, and the other location was at a former trailer park that had been constructed on property contaminated with pottery wastes. At all four locations, field measurements of total lead concentrations were made with an x-ray fluorescence (XRF) analyzer, and additional samples were collected for laboratory analysis of total lead, leachable lead (by the TCLP and SPLP), and soil lead bioaccessibility (by the SIVM). Table 2-1 presents the highest concentrations of lead measured at each of the four locations. The highest concentrations of lead measured in the field by XRF analyzers are higher than those measured in the laboratory because samples for laboratory measurements were not collected at exact locations where the highest field concentrations of lead were detected. As Table 2-1 indicates, the two locations selected for the SITE demonstration were the inactive pottery factory in Roseville, Ohio, and the trailer park, also in Roseville. The principal reasons for the selection of the inactive pottery factory in Roseville were that it appeared to have higher concentrations of lead than any of the other locations and it was more readily accessible than the other pottery factories. The trailer park was selected for the SITE demonstration primarily because use of that site would allow evaluation of the Envirobond™ technology at sites at which concentrations of lead in soil were lower than those at the pottery factories. At the time the selection was made, there was some concern that the concentrations of lead at the trailer park might be too low because they did not exceed 400 mg/kg, the residential preliminary remediation goal (PRG) for lead established by EPA (EPA 2000). However, previous field sampling conducted by OEPA with XRF analyzers had indicated that total concentrations of lead in the soil at the trailer park were well above 400 mg/kg.

2.2 Demonstration Activities

Section 2.2.1 discusses demonstration activities that were conducted before treatment. Sections 2.2.2 and 2.2.3, respectively, provide detailed descriptions of the demonstration activities that were conducted during and after the demonstration.

2.2.1 Activities Before Treatment

SITE personnel identified a total of 10 experimental units at the trailer park, and only one experimental unit at the inactive pottery factory. All the experimental units were identified through application of the provisions of a judgmental plan based on knowledge of the site and total lead measurements taken with a field XRF.

SITE Program personnel removed the vegetation (sod) from the experimental units. To facilitate the homogenization of the soil and the collection of samples, the soil in the ten experimental units at the trailer park was mixed with a garden tiller to a depth of approximately 6 inches. The soil in the one experimental unit at the inactive pottery factory was homogenized by mixing soil with a backhoe to a depth of 6 inches. The 10 experimental units in the trailer park were assigned letters (C,G,K,L,M,N,O,Q,R,T), as was the experimental unit adjacent to the inactive pottery factory (U). Each of the 10 units in the trailer park measured 5 feet wide by 5 feet long, and the single unit at the inactive pottery factory unit measured 3 feet wide by 6 feet long. The depth of the demonstration in all units was limited to the upper 6 inches of soil. Figure 2-1 shows the locations of the experimental units at the trailer park, and Figure 2-2 shows the location of the experimental unit at the inactive pottery factory.

To establish the conditions present before the application of Envirobond™, soil samples were collected from each experimental unit. However, the samples were collected differently at the two locations. At the trailer park, composite samples were collected from each of the 10 experimental units; at the inactive pottery factory, five grab samples were collected from the single experimental unit. Specific sampling procedures are described below for the trailer park and the inactive pottery factory.

Table 2-1. Summary of Maximum Concentrations of Lead Observed During Predemonstration Sampling Activities

	Maximum Lead Concentrations[1]				
Site Name and Location	Total Field (mg/kg)	Total Laboratory (mg/kg)	Leachable via TCLP (mg/L)	Leachable via SPLP (mg/L)	Bioaccessible via SIVM (%)
Trailer Park, Roseville, Ohio[2]	300	134	32.0	<0.50	47
Inactive Pottery Factory, Roseville, Ohio[2]	23,100	8,170	48.6	<0.50	31
Active Pottery Factory, Roseville, Ohio	14,500	1,080	57.9	<0.50	42
Inactive Pottery Factory, Crooksville, Ohio	2,654	793	77.1	<0.50	76

[1] The results reported represent the maximum concentrations detected, rather than a single sample from any one location. Total lead measurements in the field were made with XRF analyzers; total lead measurements in the laboratory were made by nitric acid digestion (SW-846 3050B). TCLP = toxicity characteristic leaching procedure; SPLP = synthetic precipitation leaching procedure; SIVM= simplified in-vitro method).

[2] The trailer park and the inactive pottery factory, both located in Roseville, Ohio, were selected for the SITE demonstration.

The composite soil samples for each experimental unit at the trailer park were prepared by collecting an aliquot of soil from each corner and from the middle of the experimental unit, as Figure 2-1 shows. Each aliquot was placed in a stainless-steel bowl (approximate volume: 64 ounces) with a stainless steel spoon or trowel. The technology was not to be evaluated for its ability to treat pottery chips; therefore, the soil samples were screened through a brass 3/8-inch sieve into a plastic 5-gallon bucket to remove pottery chips from the samples. Particles larger than 3/8 inch were returned to the stainless steel bowl, and the percentage of the particles, on the basis of volume, that did not pass through the sieve was estimated and recorded in the logbook. The composite sample was hand-mixed in the bucket with a stainless-steel spoon for one minute before the sample containers were filled. After mixing, fractions for the various analyses were prepared by filling the sample containers with the composited soil. Field duplicate samples were collected from two of the experimental units at the trailer park. The five grab soil samples collected from the single experimental unit at the inactive pottery factory were collected before treatment from each corner and the from middle of the experimental unit, as shown in the inset diagram on Figure 2-2. Each grab soil sample was placed in a separate stainless-steel bowl (approximate volume: 64 ounces) with a stainless-steel spoon or trowel. The grab soil sample was sieved through a brass 3/8-inch sieve into a plastic 5-gallon bucket. Particles larger than 3/8 inch were returned to the stainless steel bowl, and the percentage of the particles, on the basis of volume, that did not pass through the sieve was estimated and recorded in the logbook. Each grab sample was hand-mixed in the bucket with a stainless-steel spoon for one minute before the sample containers were filled. The grab samples from various locations were not composited. One field duplicate sample was collected from one of the grab soil samples in one of the sampling buckets.

2.2.2 Treatment Activities

RMRS applied the Envirobond™ process after the pretreatment activities were completed at each experimental unit. The Envirobond™ process powder was applied to the surface of the experimental unit using a fertilizer drop spreader. The Envirobond™ process liquid was applied over the powder using a watering can. The Envirobond™ process powder and liquid were mixed into the soil using a garden tiller. Flyash was used to adjust the soil pH of each experimental unit to approximately 7.0. A thin layer was distributed over the surface of the experimental unit and tilled into the experimental unit.

2.2.3 Activities After Treatment

SITE personnel evaluated the effectiveness of the treatment by collecting and analyzing soil samples after the technology was applied and comparing the data from those samples with the data on the untreated soil. Soil samples were collected from the experimental units treated with Envirobond™ after a minimum of 24 hours after treatment. Sampling of treated soils at the trailer park consisted of collecting and compositing five soil aliquots from each experimental unit in the same manner in which the samples of untreated soil were collected. At the inactive pottery factory, grab samples of treated soils were collected from the single experimental unit in the same manner in which the samples of untreated soil were col-

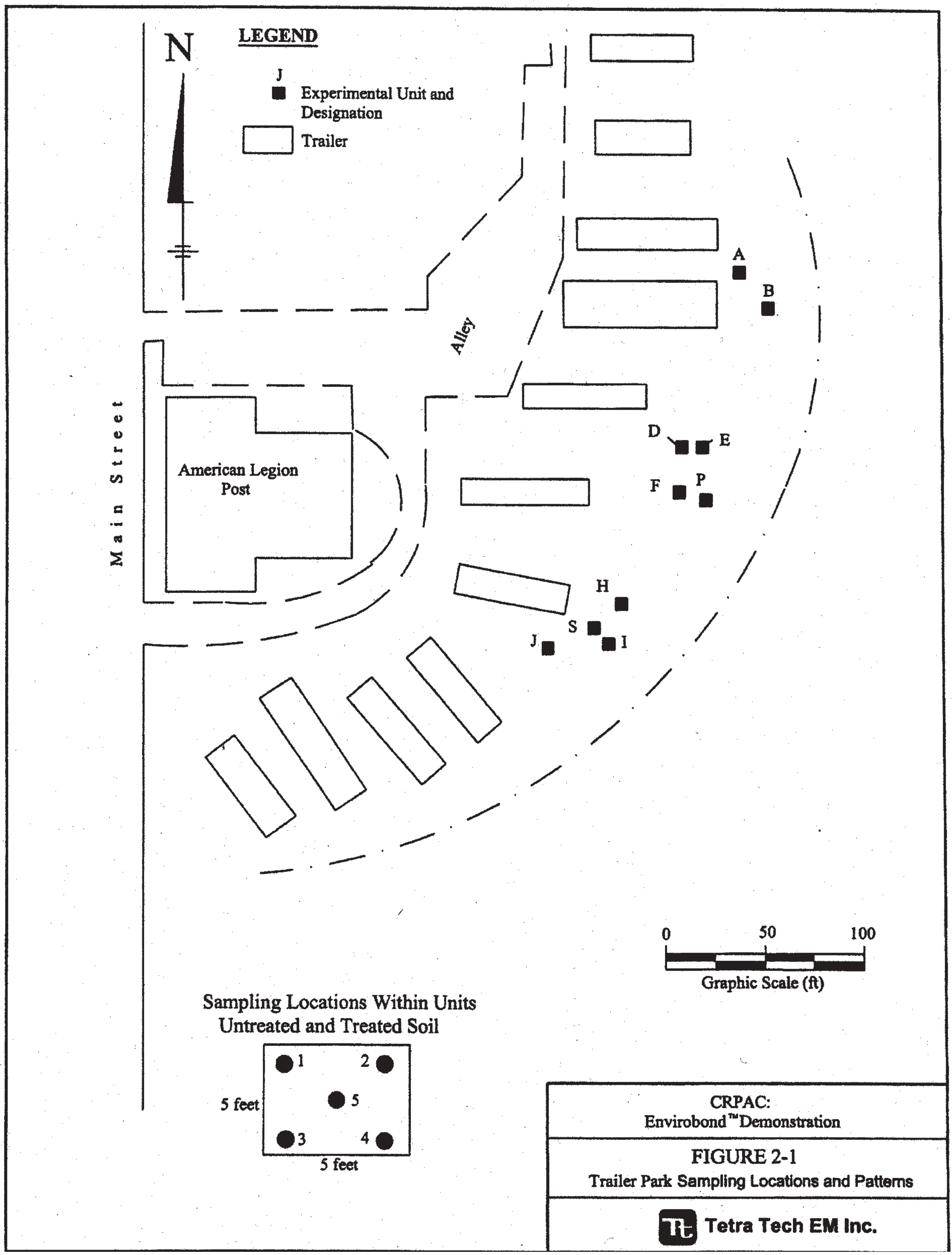


Figure 2-1. Trailer park sampling locations and patterns.

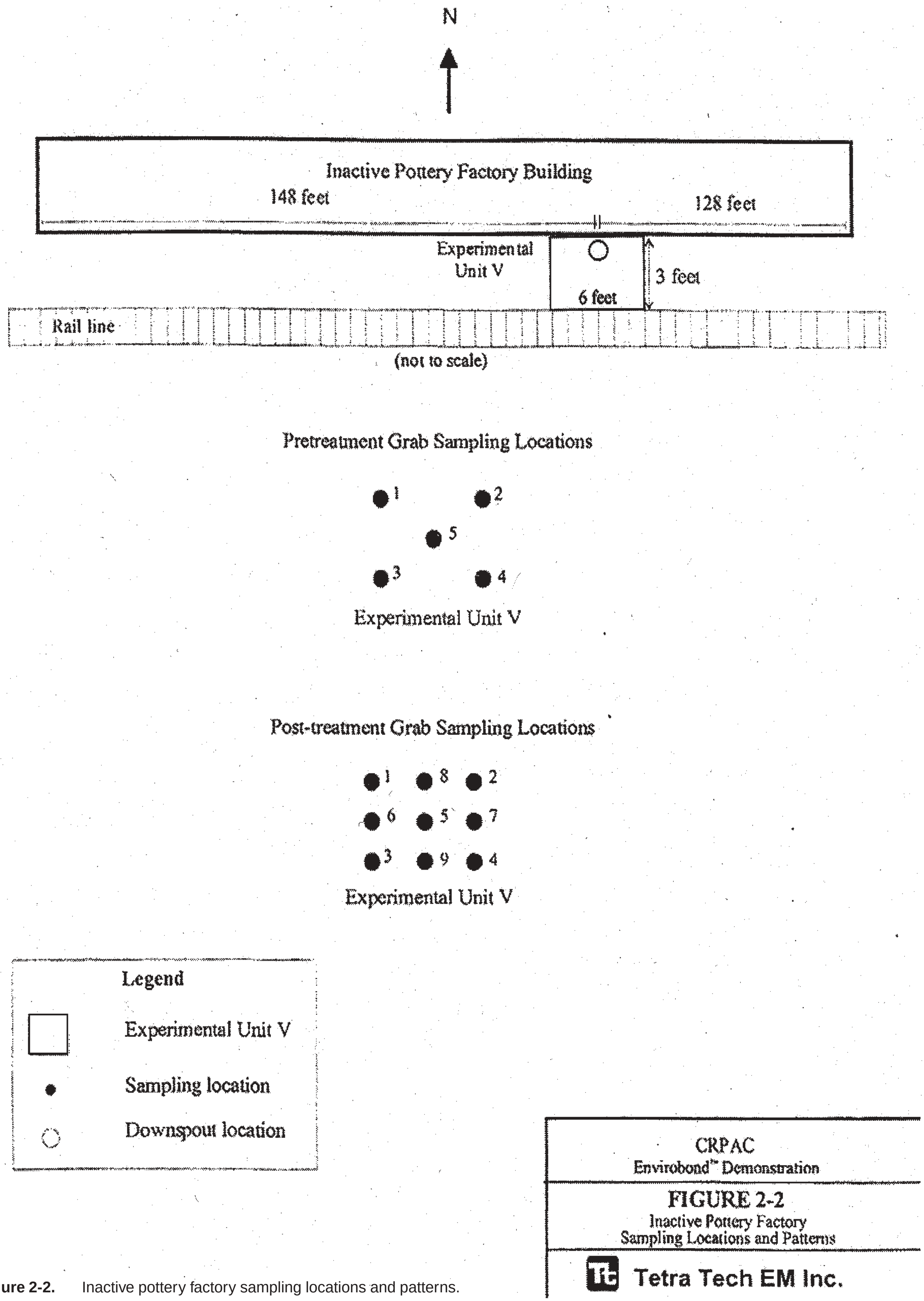


Figure 2-2. Inactive pottery factory sampling locations and patterns.

lected, except that nine grab samples were collected instead of five (see Figure 2-2) to obtain a more precise estimate of the treated sample mean.

2.3 Laboratory Analytical and Statistical Methods

The SITE program samples collected during the demonstration were analyzed by methods described in the QAPP approved by EPA (Tetra Tech EM Inc. [Tetra Tech] 1998). Statistical analyses were performed on selected analytical data to demonstrate whether the criteria set forth in the primary and secondary objectives were met. The following section presents a brief description of the analytical procedures and statistical methods used to evaluate the samples that were collected during the demonstration.

2.3.1 Laboratory Analytical Methods

Several analytical methods were used to evaluate the project objectives on the basis of the specific analyses of interest and the minimum detectable concentrations needed to achieve the project objectives. Whenever possible, methods approved by EPA were selected to analyze the soil samples collected during the demonstration. The following references were used in performing the standard analytical procedures approved by EPA:

- EPA. 1996. *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, Laboratory Manual, Volume 1A through 1C and Field Manual, Volume 2, SW-846, Third Edition, Update III*. EPA Document Control No 955-001-00000-1. Office of Solid Waste Washington, DC December. (For convenience, analytical methods from this reference are referred to as SW-846, followed by their respective analytical method number.)

- EPA. 1983. *Methods for Chemical Analysis of Water and Wastes*, EPA–600/4-79-020 and subsequent EPA-600/4-technical additions. Environmental Monitoring and Support Laboratory, Cincinnati, Ohio. (For convenience, analytical methods from this reference are referred to as MCAWW followed by their respective analytical method number.)

When standard methods were not available, or when the standard methods did not meet the project objectives, other published methods were used to analyze the soil samples. The nonstandard methods were evaluated and approved for use by EPA NRMRL before the soil samples were analyzed. Table 2-2 lists the parameters, matrices, method references, and method titles for the analytical laboratory procedures used to evaluate the SITE demonstration samples. Brief descriptions of the extraction procedures, lead analytical procedures, and nonstandard analytical procedures used in the demonstration are provided below.

Standard Extraction Procedures

Three standard extraction procedures approved by EPA were used to analyze soil samples to determine the concentrations of lead that will leach under various conditions – the TCLP, the MEP, and the SPLP. The TCLP is used to determine the mobility of contaminants in solids and multiphase waste; it simulates the initial leaching that a waste would undergo in a sanitary landfill. The MEP was designed to simulate both the initial and the subsequent leaching that a waste would undergo in an improperly designed sanitary landfill, where it would be subjected to prolonged exposure to acid precipitation. The SPLP is designed to simulate the initial leaching that a waste would undergo if it were disposed of in a monofill, where it would be subjected to exposure to acid precipitation (EPA 1996). The multiphase steps in performing the extraction procedures are described below.

The basic steps in performing the extraction procedures are:

- Determine the appropriate solution by reviewing preliminary analyses of the soil's solid content and pH of the soil

- Prepare the appropriate extraction fluid (consisting of one or more concentrated acids, depending on the procedure), diluted with distilled deionized water

- Place a specified quantity of the soil sample in an extraction vessel with a predetermined quantity of extraction fluid

- Rotate the vessel at the specified rotations per minute (rpm) for the appropriate amount of time (18 to 24 hours)

- Maintain the temperature as described in the methods

- Separate the material by filtering the content of the vessel through a glass fiber filter

- Analyze the resulting liquid for lead concentrations of lead by the procedures set forth in SW-846 methods 3050B and 6010B

Extraction Procedure for Bioaccessible Lead

The extraction procedure for soil lead bioaccessibility is presented in the SIVM. The steps in the procedure are:

- Air dry the soil sample, grind it with a mortar and pestle, and sieve it with a less than 250 microns (μm) sieve

- Analyze the sample for total lead using a XRF analyzer

- Add the sample to an aqueous extraction fluid consisting of deionized water, glycine as a buffer, and concentrated hydrochloric acid

- Maintain the sample and extraction fluid at a pH of 1.50, ± 0.05, and tumble both in a water bath at 37^{o} C for one hour, using a modified TCLP apparatus

Table 2-2. Analytical Laboratory Methods

Parameter	Matrix	Method Reference	Title of Method
TCLP Lead	Soil	SW-846 1311	Toxicity Characteristic Leaching Procedure
Soil Lead Bioaccessibility	Soil	SIVM (SBRC 1998)	In Vitro Method for Determination of Lead and Arsenic Bioaccessibility
MEP Lead	Soil	SW-846 1320	Multiple Extraction Procedure
Lead Speciation by Scanning Electron Microscopy	Soil	Standard Operating Procedure for Metal Speciation (University of Colorado 1998)	Standard Operating Procedure for Metal Speciation (Draft)
Lead Speciation by Sequential Soil Serial Extractions	Soil	Sequential Extraction Procedure for the Speciation of Particulate Trace Metals (Tessier 1979)	Sequential Extraction Procedure for the Speciation of Particulate Trace Metals
Eh	Soil	SW-846 9045C	Soil and Waste pH
pH	Soil	SW-846 9045C	Soil and Waste pH
CEC	Soil	Soil Sampling and Methods of Analysis (Canadian Society of Soil Science 1993)	Exchangeable Cations and Effective CEC by the $BaCl_2$ Method
Acid Neutralization Capacity	Soil	Environment Canada Method No. 7	Acid Neutralization Capacity
Total Lead using Nitric Acid Digestion	Soil, Plants, Water, Filters	SW-846 3050B, followed by SW-846 6010B	Acid Digestion of Sediments, Sludges, and Soils, Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES)
Oil and Grease	Soil	EPA Method 1664	Method 1664: N-Hexane Extractable Material (HEM) and Silica Gel Treated N-Hexane Extractable Material (SGT-HEM) by Extraction and Gravimetry (Oil and Grease and Total Petroleum Hydrocarbons)
Total Lead Hydrofluoric Acid Digestion	Soil	SW-846 3052, followed by SW-846 6010B	Microwave Assisted Acid Digestion of Siliceous and Organically Based Matrices, Inductively Coupled Plasma-Atomic Emission Spectrometry
SPLP Lead	Soil	SW-846 1312	Synthetic Precipitation Leaching Procedure
Phosphates	Soil	SW-846 9056	Determination of Inorganic Anions by Ion Chromatography
Humic and Fulvic Acid	Soil	Soil Sampling and Methods of Analysis (Canadian Society of Soil Science, 1993)	Soil Humus Fractions
Soil Classification	Soil	ASTM D2487-93	Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System)

(continued)

Table 2-2. Analytical Laboratory Methods (continued)

Parameter	Matrix	Method Reference	Title of Method
VOCs	Soil	SW-846 8260B	Volatile Organic Compounds by Gas Chromatograph/Mass Spectrometry
SVOCs	Soil	SW-846 8270C	Semivolatile Organic Compounds by Gas Chromatography/Mass Spectrometry: Capillary Column Technique

Notes: SW-846 = Test Methods for Evaluating Solid Waste, Volumes IA-IC: Laboratory Manual, Physical/Chemical Methods, and Volume II: Field Manual, Physical/Chemical Methods, SW-846, Third Edition, Update III.
ASTM = American Society for Testing and Materials.

- Collect 15 milliliters (mL) of extract from the extraction vessel into a 20-cubic-centimeter syringe and filter through a 0.45-micrometer (μm) cellulose acetate disk filter into a 15-mL polypropylene centrifuge tube

- Analyze the filtered extract for lead using ICP-AES according to SW-846 Method 6010B.

Table 2-3 summarizes the acids used in extraction fluids and other operational parameters of the extraction procedures.

Lead Speciation by Scanning Electron Microscopy

The percent frequency of various lead species (hereafter referred to as lead phases) in soil samples before and after treatment was determined by application of the metal speciation procedure developed by Dr. John Drexler (University of Colorado 1998). The procedure uses an electron microprobe (EMP) technique to determine the frequency of occurrence of metal-bearing phases in soil samples.

The EMP used for this analysis is equipped with four wavelength dispersive spectrometers (WDS), an energy dispersive spectrometer (EDS), a backscatter electron imaging (BEI) detector for taking photomicrographs, and a data processing system. Two of the spectrometers were equipped with synthetic “pseudocrystals” that have been developed recently for WDS applications. The pseudocrystals are known as layered dispersive elements (LDE). The materials are composed of alternating layers of boron and molybdenum of varying thicknesses and are designed to optimize the separation of individual wavelengths in the x-ray characteristic radiation spectrum. The first of the materials to be produced for WDS applications (LDE-1) was used in one of the spectrometers for the determination of oxygen. Another spectrometer was equipped with a LDE designed to detect carbon (LDE-C).

Lead speciation was determined by using the EMP to perform point counts on the samples. Point counting is a method of determining the volume fractions of constituent phases in a sample from the relative areas, as measured on a planar surface. The EMP analyzes a sample on a point-by-point basis to determine how much of a given phase is present in a sample. The point counts were performed by crossing each sample from left to right and from top to bottom with the electron beam. The amount of vertical movement for crossing depends on the magnification used and the size of the cathode-ray tube. In all cases, the movement was kept to a minimum so that no portion of the sample was missed. Two magnification settings were used for each sample, one ranging from 40 to 100 X and the other ranging from 300 to 600 X. The second magnification allowed the identification of the smallest identifiable phases (1 to 2 μm). The precision of the EMP lead speciation data was determined from duplicate analysis performed every 20 samples.

Lead Speciation by Sequential Extractions

The lead phases in the soil samples from both sites were identified by application of Tessier’s sequential extraction procedure (Tessier 1979). The soil samples were analyzed by the Laboratory for Environmental and Geological Studies at the University of Colorado, Boulder.

The soil samples were air-dried, ground with a mortar and pestle, and sieved to less than 250 μm. The procedure uses sequential chemical extractions with different reagents to determine the concentration of lead that partitions into each of several discrete metal phases. The phases include exchangeable lead, lead bound to carbonates, lead bound to iron oxide, lead bound to manganese oxide, lead bound to organic matter, and residual lead. Approximately one gram of the sample aliquot (dried weight) was used for the initial extraction. The reagent used to extract the exchangeable lead phase was magnesium chloride ($MgCl_2$) at a pH of 7.0. For the second extraction, a solution of sodium acetate and acetic acid at a pH of 5.0 was used to extract the lead bound to carbonates. For the third extraction, a hydroxyl amine hydrochloride in 25 percent acetic acid (pH ~ 2) solution was used to extract the lead bound to iron and manganese oxides. For the fourth extraction, hot hydrogen peroxide in a nitric acid solution and subsequently ammonium acetate were used to extract the lead bound to organic matter. For the final extraction, a solution of hydrofluoric and perchloric acid solution was

Table 2-3. Summary of Extraction Procedures

Method	Extraction Fluid	pH of Fluid	Temperature	Time of Extraction
TCLP	Acetic acid	4.93 ± 0.05	23°C ± 2°C	18 ± 2 hours
MEP (first extract)	Acetic acid	5.0 ± 0.2	20°C - 40°C	24 hours
MEP (second through ninth extracts)	Sulfuric and nitric acids	3.0 ± 0.2	20°C - 40°C	24 hours
SPLP	Sulfuric and nitric acids	4.20 ± 0.05	23°C ± 2°C	18 ± 2 hours
SIVM	Hycrochloric acid	1.50 ± 0.05	37°C	1 hour

used to extract the lead bound to primary and secondary minerals (the residual phase).

Oxidation-Reduction Potential

The soil samples were prepared for determining Eh using the sample preparation procedures set forth in SW-846 Method 9045C. The method consisted of preparation of a soil suspension by adding 20 mL of reagent water to 20 grams of soil. The mixture was covered and stirred for five minutes. The soil suspension was allowed to stand for one hour to allow most of the suspended clay to settle out of the suspension. The Eh then was measured according to American Society for Testing and Materials (ASTM) Test Method D1498-93, "Standard Practice for Oxidation-Reduction Potential of Water." A meter capable of reading millivolts (mV) with a reference electrode and an oxidation-reduction electrode was used to take the measurements. The meter first was allowed to warm up for two to three hours before measurements were taken. After the meter was checked for sensitivity and the electrodes were washed with deionized water, the electrodes were placed into the sample. While the sample was agitated with a magnetic stir bar, successive portions of the sample were measured until two successive portions differed by no more than 10 mV.

pH

The pH was evaluated by application of the procedures set forth in SW-846 Method 9045C. The method consisted of the preparation of a soil suspension by adding 20 mL of reagent water to 20 grams of soil. The mixture was covered and stirred for five minutes. The soil suspension was allowed to stand for one hour to allow most of the suspended clay to settle out of the suspension. A pH meter was allowed to warm up for two to three hours before measurements were taken. After the meter was checked for sensitivity and the electrodes were washed with deionized water, the electrodes were placed in the clear supernatant portion of the sample. If the temperature of the sample differed by more than 2°C from that of the buffer solution, the pH values measured were corrected for the temperature difference.

Cation Exchange Capacity

One sample from the untreated and treated soil samples from each site was selected for evaluation of CEC, which was determined by the barium chloride ($BaCl_2$) method. The $BaCl_2$ method provides a rapid means of determining the exchangeable cations and the "effective" CEC of a wide range of soil types. By that method, CEC is calculated as the sum of exchangeable cations (Ca, Mg, K, Na, Al, Fe, and Mn). The procedure consisted of the following steps:

- The soil sample was air-dried, ground using a mortar and pestle, and sieved to less than 250 μm
- Approximately 0.5 gram of soil was placed into a 50-mL centrifuge tube with 30.0 mL of 0.1 molar $BaCl_{2,}$ and the mixture was shaken slowly on an end-over-end shaker at 15 rpm for 2 hours
- The mixture was centrifuged for 15 minutes, and the supernatant portion was filtered through a Whatman No. 41 filter paper
- The cations were analyzed with an atomic absorption spectrophotometer.

Acid Neutralization Capacity

The acid neutralization capacity of the soil was determined by application of Environment Canada Method No. 7. The soil sample was air-dried, ground using a mortar and pestle, and sieved to less than 250 μm. The amount of neutralizing bases, including carbonates, was then determined by treating each sample with a known excess of standardized hydrochloric acid. The sample and acid were heated to allow completion of the reaction between the acid reagent and the neutralizers in the soil sample. The calcium carbonate equivalent of the sample was obtained by determining the amount of unconsumed acid by titration with standardized sodium hydroxide.

Lead Analytical Procedures

Two procedures were used to determine the lead concentrations in the soil. One analytical procedure used a nitric acid solution to measure all but the most stable forms of lead in the sample, and the other procedure used hydrofluoric acid to measure all of the lead in the sample. The nitric acid digestion procedure involved digesting approximately one gram of soil with a solution of nitric acid, hydrogen peroxide, and hydrochloric acid. The mixture was heated to 95°C, ± 5°C, for approximately two hours. The digestate was filtered through Whatman No. 41 filter paper into a flask and analyzed for lead ICP-AES, as described in SW-846 Method 6010B.

The hydrofluoric acid digestion procedure involved heating approximately one gram of soil in a solution containing nitric and hydrofluoric acids to 180°C, ± 5°C, for approximately 9.5 minutes. The digestate was filtered through Whatman No. 41 filter paper into a flask, and the filtrate was analyzed for lead by ICP-AES, as described in SW-846 Method 6010B.

Soil Classification

Soil classification consisted of determining the particle size distribution, liquid limit, and plasticity index of the soil samples. That information was used to classify the soil according to basic soil group, assigning a group symbol and name. The particle size distribution was determined by sieving the dried soil samples through a series of sieves and determining the percentage by weight that was retained on the sieves. The liquid limit is the water content (measured as percent moisture) at which a trapezoidal groove cut in moist soil (in a special cup) closes being tapped 25 times on a hard rubber plate. The plastic limit is the water content at which the soil breaks apart when rolled by hand into threads of 1/8-inch diameter. The plasticity index is determined by first determining the liquid and plastic limits and then subtracting the plastic limit from the liquid limit.

Humic and Fulvic Acids

Humic and fulvic acids were extracted from the soil samples and quantified through the use of a sodium hydroxide solution, as described below:

- Air dry 15 g of soil, grind it to less than 250 Fm, and place it in a 250-mL plastic centrifuge bottle
- Add 150 mL of 0.5 molar hydrochloric acid, let the mixture sit for one hour, and then centrifuge it for 15 minutes and discard the supernatant portion
- Add 150 mL of deionized water to the centrifuge bottle and mix it to wash the soil of remaining acid; centrifuge again for 15 minutes and discard the supernatant portion
- Add 150 mL of 0.5 molar sodium hydroxide to the centrifuge bottle and flush the head space with oxygen-free nitrogen gas
- Place the bottle on an end-over-end shaker for 18 hours
- Centrifuge the mixture for 15 minutes, decant the supernatant portion, and separate that portion into the humic and fulvic fractions by acidifying the extract to a pH of 1.5; the precipitate is the humic acid fraction, and the supernatant portion is the fulvic acid fraction

2.3.2 Statistical Methods

This section provides a brief overview of the statistical methods that were used to evaluate the data from the SITE demonstration. The methods included assessing the distribution of sample data and calculating specific parametric and distribution-free statistics.

2.3.2.1 Determination of the Distributions of the Sample Data

A preliminary assessment of distribution of data was conducted to determine the approximate statistical distribution of the sample data when parametric hypothesis tests were performed. For the evaluation of the data collected for the primary and secondary objectives, sample data distributions were determined by the following methods: (1) common graphical procedures, including histograms, box-plots, stem-and-leaf plots, and quartile-quartile plots, and (2) formal testing procedures, such as the Shapiro-Wilk test statistic, to determine whether a given data set exhibits a normal distribution.

2.3.2.2 Parametric and Distribution-free Test Statistics

Various testing procedures were employed to determine whether there were any significant differences between concentrations of lead and concentrations of other analytes of interest in the treated soil and the untreated soil. Table 2-4 summarizes the statistical procedures used in evaluating the analytical results associated with each of the objectives of the SITE demonstration. As the table shows, all the parametric statistical procedures used to evaluate the data from the demonstration involved the Student's t-tests. Paired Student t-tests were conducted on data collected from the trailer park, and unpaired Student t-tests were required on data from the pottery factory because of the unequal sizes of samples of treated and untreated soils from that location (see Figure 2-2). In addition, the formula for the Student's t-test was adjusted for evaluation of P2, because the estimator used for that objective (percent reduction of percent bioavailable lead) required manipulation to avoid the creation of a cauchy (nonnormal) distribution, which cannot be evaluated by a Student's t-test. Data points obtained from the trailer park for evaluation of P2 (sufficient data from the pottery factory were not available for application of a meaningful Student's t-test for evaluation of P2) were evaluated in a paired Student's t-tests, using the following formula:

$$y_i = x_{ti} - x_{ui}\,,\ y_m \sum_{i=1}^{n} y_i \,/\, n, \text{and } S_y^{\,2} = \sum_{i=1}^{n} (y_i - y_m)^2 / (n-1) \qquad \text{(2-1)}$$

Table 2-4. Summary of Statistical Procedures Used to Evaluate Each of the Objectives of the Demonstration

Objective	Test Method/ Test Variable	Statistical Method/Acceptance Criterion for Meeting the Objective
P1: Determine whether leachable lead in soil can be reduced to concentrations that comply with the alternative UTS for contaminated soil that are codified at 40 CFR part 268.49[1].	TCLP/Mean concentration of lead in extract (mg/L)	Student's t-test formula at the 0.05 level of significance/Mean concentration of the treated soil must be less than 7.5 mg/L or 90 percent of the mean concentration in untreated soil, whichever is the higher value.
P2: Determine whether the portion of total lead in soil that is "bioaccessible," as measured by an experimental method, can be reduced by at least 25 percent[2].	SIVM/Mean percentage of total lead extracted by the method	Student's t-test formula at the 0.05 level of significance/Mean percentage of total lead in the extract from the treated soil must be at least 25 percent lower than the mean percentage of total lead in the extract from the untreated soil.
S1: Evaluate the long-term chemical stability of the treated soil.	MEP/Mean lead concentration in each extract (mg/L)	Review of test results/Concentrations of all extracts from the treated soils must be lower than 5 mg/L (a nominal concentration that would be expected to meet or exceed cleanup goals at some sites).
	SEM lead speciation/Percent distribution of lead among various lead phases[3]	Review of test results/Percent frequencies of more soluble and less soluble phases of lead in the treated and untreated soils must be lower and higher, respectively.
	Sequential extraction/Mean concentration of lead in each phase (mg/L)	Student's t-test formula at the 0.05 level of significance/Mean concentrations of the more soluble and less soluble phases of lead in the treated and untreated soils must be lower and higher, respectively.
	Eh (mV)	Student's t-test formula at the 0.05 level of significance/Mean Eh of the treated soil must be lower than that of the untreated soil.
	pH	Student's t-test formula at the 0.05 level of significance/Mean pH of the treated soil must be higher than that of the untreated soil and 7.0.
	CEC/Milliequivalents per gram (meq/g)	Review of test results/CEC must be increased, as indicated by a qualitative review of statistical summary data.
	Acid neutralization capacity/meq/g	Review of test results/Neutralization capacity must be increased, as indicated by a qualitative review of statistical summary data.
	Total lead–nitric acid/Mean lead concentration of lead (mg/kg)	Student's t-test formula at the 0.05 level of significance/Mean concentration of lead in the treated soil must be lower than that in the untreated soil.

(continued)

Table 2-4. Summary of Statistical Procedures Used to Evaluate Each of the Objectives of the Demonstration (continued)

Objective	Test Method/ Test Variable	Statistical Method/Acceptance Criterion for Meeting the Objective
	Total lead–hydrofluoric acid /Mean concentration of lead (mg/kg)	Student's t-test formula at the 0.05 level of significance/Mean concentration of lead in the treated soil must not be higher or lower than that in the untreated soil.
	SPLP lead/Mean concentration of lead in the extract (mg/L)	Student's t-test formula at the 0.05 level of significance/Mean concentration of lead in the extract of the treated soil must be less than 5 mg/L (a nominal concentration that would be expected to meet or exceed cleanup goals at some sites).
	Total phosphate/Mean concentration of phosphate	Review the results/Mean concentration of total phosphates in the treated soil must not be significantly higher or lower less than that in the untreated soil.
	SPLP phosphate/Mean concentration of phosphate in the extract (mg/L)	Review the results/Mean concentration of phosphate in the extract of the treated soil must be less than or equal to that of the untreated soil.
S2: Demonstrate that the application of Envirobond™ did not increase the public health risk of exposure to lead.	Total lead/Mean concentration of lead in the air (mg/m^3)	Review of test results/Concentrations of airborne lead must not exceed NAAQS limits for lead.
S3: Document baseline geophysical and chemical conditions in the soil before the application of Envirobond™.	Soil classification, total VOCs, SVOCs, oil and grease, and humic and fulvic acids	Review of test results/Identify results that appear unusual in light of the location and history of the site (no specific acceptance criteria were established for S3).
S4: Document operating and design parameters for Envirobond™.	Cost analyses	Present cost data/No specific acceptance criteria were established for S4.

[1] Objective P1 was evaluated statistically only on analytical results from the inactive pottery factory; only three samples pertinent to that objective were collected from the trailer park.
[2] Achievement of P2 was evaluated only at the trailer park.
[3] SEM lead speciation was conducted only on soils collected from the trailer park.

where x_{ti} and x_{ui} represent the ith observations about treated and untreated soils, *n* represents the sample size, y_i represents the calculated difference between the ith observations, y_m represents the arithmetic mean of the calculated differences, and S_y^2 represents the calculated variance.

The calculation results in the following t-test statistic:

$$t = \frac{y_m}{\sqrt{(S_y{}^2)/n}} \tag{2-2}$$

which follows a t-distribution with *n-1* degrees of freedom. The test then can be used to determine whether the observed mean difference varies significantly from 0.

The formula used for testing for a 100(1-r_0) percent reduction in the arithmetic mean contaminant levels between normally distributed (paired) data on treated and untreated soils for P2 was:

$$\hat{C}_R = C_T - C_U(1-r_o) \ where \ C_T = \sum_{i=1}^{n} x_{th} / n \ and \ C_U = \sum_{i=1}^{n} x_{uh} / n \tag{2-3}$$

where x_{th} and x_{uh} represent the ith observations about the treated and untreated soils, *n* represents the sample size, C_T and C_U represent the arithmetic mean of observations about the treated and untreated soils, r_0 represents the proportionality reduction factor (for example, if testing for a 25 percent reduction, $r_0 = 0.25$), and $\hat{C}_R$ represents the computed test statistic. The variance for the estimate was calculated as follows:

$$Var(\hat{C}_R) = \left[S_T{}^2 + (1-r_0)^2 S_U{}^2 - 2(1-r_0)S_{UT}\right] / n \tag{2-4}$$

where $S_T{}^2$ and $S_U{}^2$ represent the calculated sample variance for the treated and untreated soils, S_{UT} represents the calculated sample covariance between the soils, and the term Var( ) symbolizes "the variance of." However, the following more convenient calculation was applied to the individual, paired observations:

$$y_i = x_{tj} - (1 - r_0)x_{uj} \, , y_m = \sum_{i=1}^{n} y_i \, / \, n \text{ and } S_y^{\;2} = \sum_{i=1}^{n} (y_i - y_m)^2 \, / \, (n-1) \qquad (2\text{-}5)$$

where all terms are defined as before, since it can be easily shown that:

$$y_m = \hat{C}_R \text{ and } S_y^{\;2} = Var(\hat{C}_R). \qquad (2\text{-}6)$$

That calculation resulted in the following t-test statistic:

$$t = \frac{y_m}{\sqrt{(S_y^{\;2}) \, / \, n}} \qquad (2\text{-}7)$$

which follows a t-distribution with *n-1* degrees of freedom.

Bootstrap resampling analysis, a distribution-free analysis, was performed when assumptions about the distribution of the sample data were not met. Bootstrap resampling was used to estimate means, confidence intervals, or construct hypothesis tests. Bootstrap resampling techniques also were used to check the results produced by various parametric tests. A bootstrap analysis was performed on the soil lead bioaccessibility data on the paired samples. The bootstrap analysis was performed by drawing *N* samples of size *n* from the observed individual percent reduction (PR) sample values defined as:

$$PR_i = 100\left(1 - \frac{x_{ti}}{x_{ui}}\right) \qquad (2\text{-}8)$$

where x_{ti} and x_{ui} once again represent the i^th observations about treated and untreated soils, *n* represents the sample size, and N represents the number of times the simulations were performed (*N* = 1000 and *n* = 10 for this study). The bootstrap samples then were used to calculate: (1) the observed mean percent reduction; (2) a $100(1-\alpha)\%$ confidence interval for this mean estimate, using the observed bootstrap cumulative distribution function; and (3) the proportion of sample means that exceed a given $100(1- r_0)\%$ threshold (that calculation represents a bootstrap version of a hypothesis test).

2.4 Results of the SITE Demonstration

The following sections present the analytical data relevant to each objective of the demonstration and the results of evaluations of those data, including summaries of statistical calculations. Section 2.4.1 addresses P1, Section 2.4.2 addresses P2, and sections 2.4.3 through 2.4.6 address S1 through S4, respectively.

2.4.1 Evaluation of P1

Determine whether leachable lead in soil can be reduced to concentrations that comply with the alternative UTS for contaminated soil that are codified at 40 CFR part 268.49.

The treatment standards for contaminated soil that are codified at 40 CFR part 268.49 require that the concentrations of lead in the treated soil, as measured by the TCLP, must be less than 7.5 mg/L or at least 90 percent lower than those in the untreated soil, whichever is the higher concentration. Soil samples were collected from the experimental unit at the inactive pottery factory before and after treatment to assess the Envirobond™ treatment process. Table 2-5 summarizes the TCLP lead data for the inactive pottery factory site.

The results of the statistical analysis of those data, shown in Table 2-6, demonstrate that the mean concentration of TCLP lead in treated soil from the inactive pottery factory was significantly less than 7.5 mg/L; in fact, the results reflect a probability of less than 0.001 (or 1 in 1,000) that the actual mean concentration of TCLP lead in the treated soils is higher than 7.5 mg/L. Therefore, it was concluded that Envirobond™ acheived the first primary objective (P1) of the SITE demonstration. In addition, Envirobond™ exceeded P1 in that the mean concentration of TCLP lead in the untreated soil was reduced by more than 99 percent.

Data from the trailer park were not used to evaluate P1 because TCLP lead concentrations in all of the treated and untreated soil samples from this location were either at or only slightly higher than the detection limit of 0.05 mg/L.

2.4.2 Evaluation of P2

Determine whether the portion of total lead in soil that is "bioaccessible," as measured by an experimental method, can be reduced by at least 25 percent.

The objective was evaluated by collecting samples of untreated and treated soil from the trailer park for soil lead bioaccessibility and analyzing the samples by the SBRC's SIVM. Table 2-7 presents the results of the SIVM analysis of the untreated and treated soil samples. Soil lead bioaccessibility is the ratio of the amounts of lead that is solubilized during the extraction to the total amount of lead in the soil sample. The concentrations of bioaccessible lead in the untreated soils (mg/kg) are calculated on the basis of total lead measured in the extract and the mass of the soil extracted during the test. The concentrations then are divided by the total concentration of lead measured in the untreated soil to arrive at the percentage of bioaccessible lead in the untreated soils. Identical measurements and calculations are used to calculate the percentage of bioaccessible lead in the treated soils.

Data analysis for the objective consisted of performance of an assessment of data distribution and a parametric test (t-test). An assessment of the results of the validity of the parametric test was performed by the conduct of a distribution free test (bootstrap analysis).

Table 2-5. TCLP Lead Results for the Inactive Pottery Factory Site			
Experimental Unit	Sampling Location	Untreated (mg/L)	Treated (mg/L)
V	1	421	2.0
V	2	563	1.5
V	3	320	1.4
V	4	247	<0.50
V	5	358	1.5
V	6	n/s	2.1
V	7	n/s	0.94
V	8	n/s	1.7
V	9	n/s	1.5
Note: n/s = Not sampled (see Figure 2-2)			

Table 2-6. TCLP Lead Summary and Test Statistics for the Inactive Pottery Factory Site				
Untreated Mean (mg/L)	Treated Mean (mg/L)	Percent Reduction	Treated 95% UCL (mg/L)	Probability That the Actual Treated Mean Is >7.5 mg/L (Students t-test)
381.8	1.41	99.63%	1.81	<0.001

Table 2-7. Soil Lead Bioaccessibility Results							
	Untreated Results			Treated Results			Summary
Unit	Total Lead (mg/kg)	Bioaccessible Lead (mg/kg)	Percentage Lead Bioaccessibility	Total Lead (mg/kg)	Bioaccessible Lead (mg/kg)	Percentage Lead Bioaccessibility	Percent Reduction
A	676	346.04	51.2%	432	162.65	37.7%	26.4%
B	380	191.39	50.4%	246	82.85	33.7%	33.1%
D	3066	1940.58	63.3%	3159	1520.11	48.1%	24.0%
E	3371	2103.89	62.4%	2254	1054.99	46.8%	25.0%
F	4508	2649.39	58.8%	2760	1259.02	45.6%	22.4%
H	1889	849.37	45.0%	1236	513.68	41.6%	7.6%
I	787	326.71	41.5%	463	257.40	55.6%	-33.9%
J	1254	594.92	47.4%	826	378.68	45.8%	3.4%
P	1707	831.88	48.7%	1127	508.59	45.1%	7.4%
S	1281	479.92	37.5%	845	326.15	38.6%	-3.0%

The assessment of data distribution suggested that the soil lead bioaccessibility data followed a normal distribution (for both untreated and treated soils). Therefore, the standard t-test formula for testing for a 100 ($1-r_0$)% reduction in the arithmetic mean was used, with r_0 equal to 0.25. Table 2-8 presents a summary of the parametric test statistics, which can be used to determine whether a reduction of at least 25 percent in the soil lead bioaccessibility has been achieved. To conclude that reduction of at least 25 percent has occurred at a significance level of alpha 0.05, the observed t-score should be less than -1.812. On the basis of that criterion, the percent reduction achieved appears to be less than 25 percent.

An assessment of the validity of the results of the parametric test was performed through the conduct of a bootstrap analysis of the sample values. For the bootstrap analysis, samples of size 10 were drawn with replacement 1,000 times from the Envirobond™ soil lead bioaccessibility data. Table 2-9 summarizes the results of that analysis.

The calculated percent reduction in soil lead bioaccessibility was 12.07 percent, with a calculated standard deviation of 6.07 percent and a 95 percent confidence interval of -0.4 percent to 22 percent. Only two of the 1,000 bootstrap calculations were found to exceed a percent reduction value of 25 percent. Therefore, the results of the bootstrap analysis support the results of the parametric test, which indicate that Envirobond™ did not appear to achieve the goal of at least 25 percent reduction in soil lead bioaccessibility in soils from the trailer park.

2.4.3 Evaluation of Objective S1

Demonstrate the long-term chemical stability of the treated soil.

Various analytical procedures that are indicative of long-term chemical stability were selected for use in evaluating S1. For the demonstration, the long-term chemical stability of the treated soil was evaluated by comparing the analytical results for the untreated soil samples with those for the treated soil samples, using leaching procedures, lead speciation methods, and other inorganic chemical procedures, including: the MEP, lead speciation by scanning electron microscopy, lead speciation by the sequential soil serial extraction procedure, Eh, pH, cation exchange capacity, acid neutralization capacity, total lead in soil (as determined by two different methods), leachable lead by the SPLP, total phosphates, and leachable phosphates. The discussions below describe the analytical methods, how the methods were used to indicate long-term chemical stability, and the analytical results for each method.

MEP

The MEP was designed to simulate both the initial and subsequent leaching that a waste would undergo in a sanitary landfill. The criterion established for determining whether the results of the MEP demonstrate achievements of S1 (long-term chemical stability) required that the concentrations of lead leached from the treated samples were less than 5.0 mg/L. The criterion is a nominal concentration that would be expected to meet or exceed cleanup goals at some sites; therefore, it is not provided in any federal laws or regulations. Although the MEP was not designed for use on untreated soils, the demonstration plan included analysis of untreated soils using the MEP to provide a basis of comparison with the test results on the treated soils.

Table 2-10 lists the analytical results for the MEP. The data from untreated soil at the trailer park site indicated that the MEP analytical results were consistently less than 5.0 mg/L. The data on treated soil from the trailer park site indicated that the MEP analytical results were also consistently less than 5.0 mg/L for the extraction period.

The untreated soils at the five sampling locations at the inactive pottery factory site contained greater than or equal to 5.0 mg/L of leachable lead. Figures 2-3 through 2-7 display the MEP results for the five untreated samples that were equal to or greater than 5.0 mg/L with the corresponding results from analysis of treated soil.

The MEP lead concentrations of the treated soils at the inactive pottery factory were reduced below 5.0mg/L except for the result for the Day 4 extraction from sampling location 1 (5.1 mg/L). Other than this one slightly elevated result, the MEP analytical results indicate that the Envirobond™ process is effective in reducing the concentration of lead that will leach under repetitive precipitation of simulated acid rain conditions. Therefore, the long-term stability of the treated soil appears to have been enhanced by the addition of the Envirobond™ process.

Table 2-8. Parametric Test Statistics Soil Lead Bioaccessibility Data

Statistic	Data
Value of C_R[1]	5.48 %
Standard deviation	8.27
t-score (H_o: C_R greater than or equal to 0)	2.093
Level of significance	0.9686

[1] $C_R = C_t - C_u (1-r_o)$ (see Section 2.3.2.2)

Table 2-9. Bootstrap Statistical Results for Bioavailable Lead Difference Data

Statistic	Data
Mean	12.07%
Standard deviation	6.07%
95% confidence interval	(-0.4%, 22%)
Number of percent reduction samples > 25%	2/1,000

Table 2-10. MEP Analytical Results

Experimental Unit	Untreated/ Treated	Initial Extract (mg/L)	Day 1 (mg/L)	Day 2 (mg/L)	Day 3 (mg/L)	Day 4 (mg/L)	Day 5 (mg/L)	Day 6 (mg/L)	Day 7 (mg/L)	Day 8 (mg/L)	Day 9 (mg/L)	Day 10[1] (mg/L)
Trailer Park												
A	Untreated	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	0.052	<0.050	
A	Treated	0.140	0.058	0.057	<0.050	0.062	<0.050	<0.050	<0.050	<0.050	0.058	<0.050
A (Duplicate)	Untreated	0.220	0.120	0.160	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	
A (Duplicate)	Treated	0.110	0.073	0.063	0.140	0.065	<0.050	<0.050	<0.050	<0.050	0.089	<0.050
B	Untreated	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	0.055	<0.050	0.057	<0.050	
B	Treated	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	0.052	<0.050	
D	Untreated	0.190	0.140	0.110	0.062	0.058	0.210	0.550	0.210	1.400	0.200	
D	Treated	0.420	0.330	0.400	0.400	0.470	0.260	0.100	<0.050	<0.050	0.170	0.062
E	Untreated	0.580	0.150	0.210	0.089	0.062	0.160	0.720	0.340	1.000	0.490	
E	Treated	0.400	0.670	0.220	0.160	0.190	0.310	0.210	0.200	0.340	<0.050	
F	Untreated	0.250	1.030	0.160	0.095	0.085	0.400	2.200	0.690	3.200	2.000	
F	Treated	0.510	0.290	0.510	0.330	0.100	<0.050	<0.050	0.067	0.088	<0.050	
H	Untreated	0.180	0.110	0.140	0.067	<0.050	0.640	1.700	0.620	1.300	0.490	
H	Treated	0.460	<0.050	<0.050	0.051	0.100	<0.050	<0.050	<0.050	<0.050	<0.050	
I	Untreated	<0.050	<0.050	<0.050	<0.050	<0.050	0.160	0.240	0.077	0.240	0.310	0.098
I	Treated	<0.050	<0.050	<0.050	0.110	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	
J	Untreated	1.400	0.550	0.160	<0.050	0.052	<0.050	0.200	0.270	0.190	0.250	0.056
J	Treated	<0.050	0.150	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	
P	Untreated	<0.050	<0.050	0.090	<0.050	<0.050	0.050	0.390	0.260	0.610	0.150	
P	Treated	0.051	0.085	0.270	0.120	<0.050	<0.050	<0.050	<0.050	0.069	<0.050	
S	Untreated	0.065	0.280	0.065	<0.050	<0.050	0.140	0.420	0.150	0.360	0.210	
S	Treated	0.083	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	

Note: [1] After the initial daily extract, nine extractions are performed on each of the following nine days; if the lead concentration is higher in Day 9 than the concentrations in Days 7 or 8, the extractions are repeated until concentrations decrease, or until Day 12. Results for Day 10 were not recorded if there was no increase in lead concentrations from Days 7 or 8 to Day 9.

(continued)

Lead Speciation by Scanning Electron Microscopy

This procedure used an EMP technique to determine the frequency of occurrence of 18 lead-bearing phases in soil samples from the trailer park location only. For the demonstration, the mean of the percent frequency of each lead phase was evaluated with regard to the effect the change in that phase will have on the long-term chemical stability of the treated soil. The long-term chemical stability of a soil is enhanced if the application of Envirobond™ increased the frequency of the phases having low solubilities (such as the lead phosphate phase) and decreased the frequency of the species that are highly soluble (such as the lead metal oxide phase). Because of the volume of data generated from the procedure (10 samples for each of 18 metal-bearing phases), the mean of the percent frequency of each phase was determined to compare the analytical

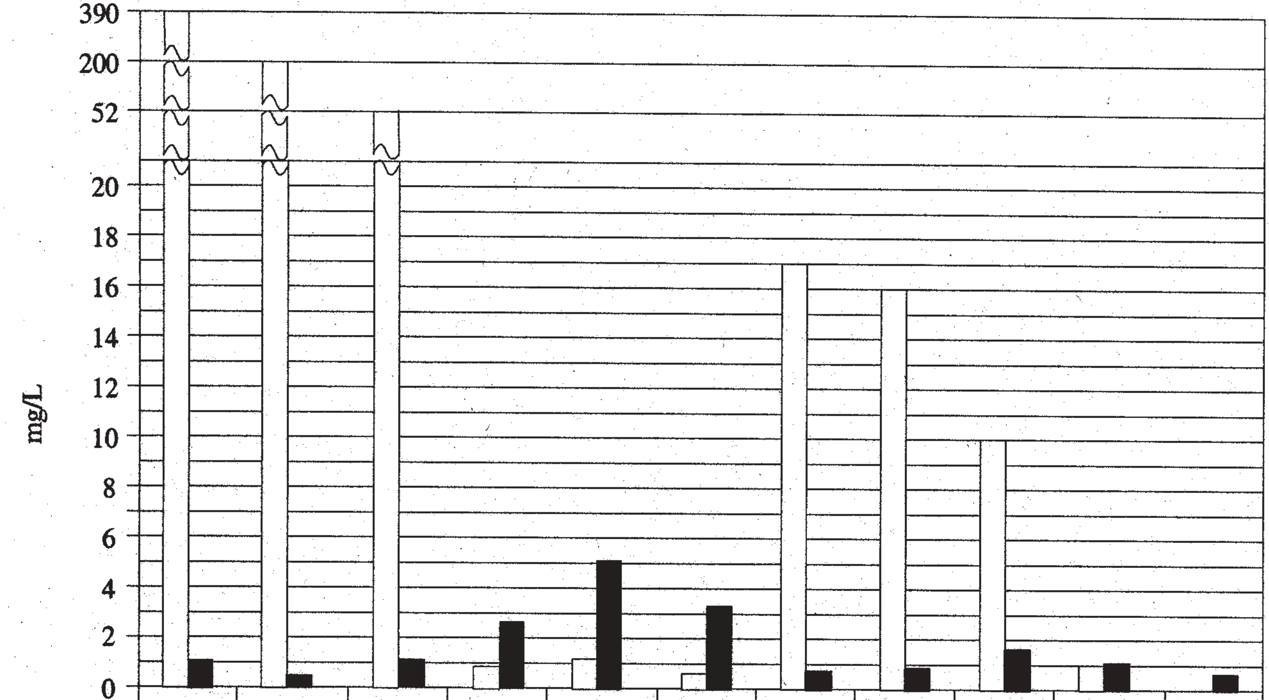
Table 2-10. MEP Analytical Results (continued)

Experi-mental Unit	Untreated/ Treated	Initial Extract (mg/L)	Day 1 (mg/L)	Day 2 (mg/L)	Day 3 (mg/L)	Day 4 (mg/L)	Day 5 (mg/L)	Day 6 (mg/L)	Day 7 (mg/L)	Day 8 (mg/L)	Day 9 (mg/L)	Day 10[1] (mg/L)
Inactive Pottery Factory												
U Location 1	Untreated	390	200	52	0.890	1.200	0.570	17	16	10	1.000	
U Location 1	Treated	1.100	0.520	1.100	2.600	5.100	3.300	0.720	0.900	1.600	1.100	0.640
U Location 2	Untreated	420	160	31	0.890	0.390	0.370	16	20	17	9.5	
U Location 2	Treated	0.760	0.320	0.750	1.600	2.200	1.500	0.500	0.640	1.100	1.200	0.770
U Location 3	Untreated	220	76	18	0.210	0.410	1.400	1.300	0.910	1.400	0.210	0.140
U Location 3	Treated	0.530	0.230	0.920	1.600	2.300	2.300	0.500	0.790	1.400	1.100	0.960
U Location 4	Untreated	21	0.230	1.500	0.240	0.190	0.280	1.300	0.160	0.490	0.140	
U Location 4	Treated	0.270	0.092	0.270	0.640	0.580	0.290	0.550	0.490	0.870	0.960	0.750
U Location 5	Untreated	130	16	1.900	0.560	0.360	15	9	1.700	7.600	0.250	
U Location 5	Treated	0.940	1.700	2.600	1.300	1.200	0.390	0.900	0.540	0.990	1.200	0.890
U Location 6	Treated	0.600	1.000	2.000	1.400	0.900	0.410	0.980	0.650	1.400	1.200	
U Location 7	Treated	0.390	0.800	0.580	0.970	1.300	0.310	0.940	0.800	1.100	0.990	
U Location 8	Treated	0.190	0.140	0.110	0.062	0.058	0.210	0.550	0.210	1.400	0.200	
U Location 9	Treated	0.940	0.440	0.850	1.200	3.400	2.500	0.630	1.100	1.300	1.100	0.850

Note: [1] After the initial daily extract, nine extractions are performed on each of the following nine days; if the lead concentration is higher in Day 9 than the concentrations in Days 7 or 8, the extractions are repeated until concentrations decrease, or until Day 12. Results for Day 10 were not recorded if there was no increase in lead concentrations from Days 7 or 8 to Day 9.

results for untreated and treated soils. The unpublished TER provides a table of the raw lead speciation data. The TER is available upon request from the EPA work assignment manager (see Section 1.4 for contact information).

Table 2-11 shows the mean percent frequency of each metal phase for untreated and treated soils, as well as other descriptive statistics. The data suggest that there were potentially significant changes from untreated to treated soils for only 4 of the 18 phases that were evaluated. The frequency of the lead silica phosphate phase increased between the values for untreated and treated soils, a condition that would be indicative of an increase in the long-term chemical stability of the soil. Also indicative of chemical stability are the apparent reduction in the iron oxide phase of lead. The results also indicate that there were decreases in the glass and slag phases of lead, which indicates a reduction in stability from the untreated to the treated soils. Because of the nature of the speciation test, it is not possible to identify the net result of the changes in the frequencies of those four phases. Therefore, the lead speciation results were not unanimously consistent with the attainment of objective S1; however, it



	EP-Tox	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
☐ Pretreatment	390	200	52	0.890	1.200	0.570	17.000	16.000	10.000	1.000	
■ Post-treatment	1.100	0.520	1.100	2.600	5.100	3.300	0.720	0.900	1.600	1.100	0.640

Extraction Day

Figure 2-3 . MEP lead results for inactive pottery factory sampling Location 1.

appears that those results suggest that Envirobond™ can enhance the long-term stability of treated soil.

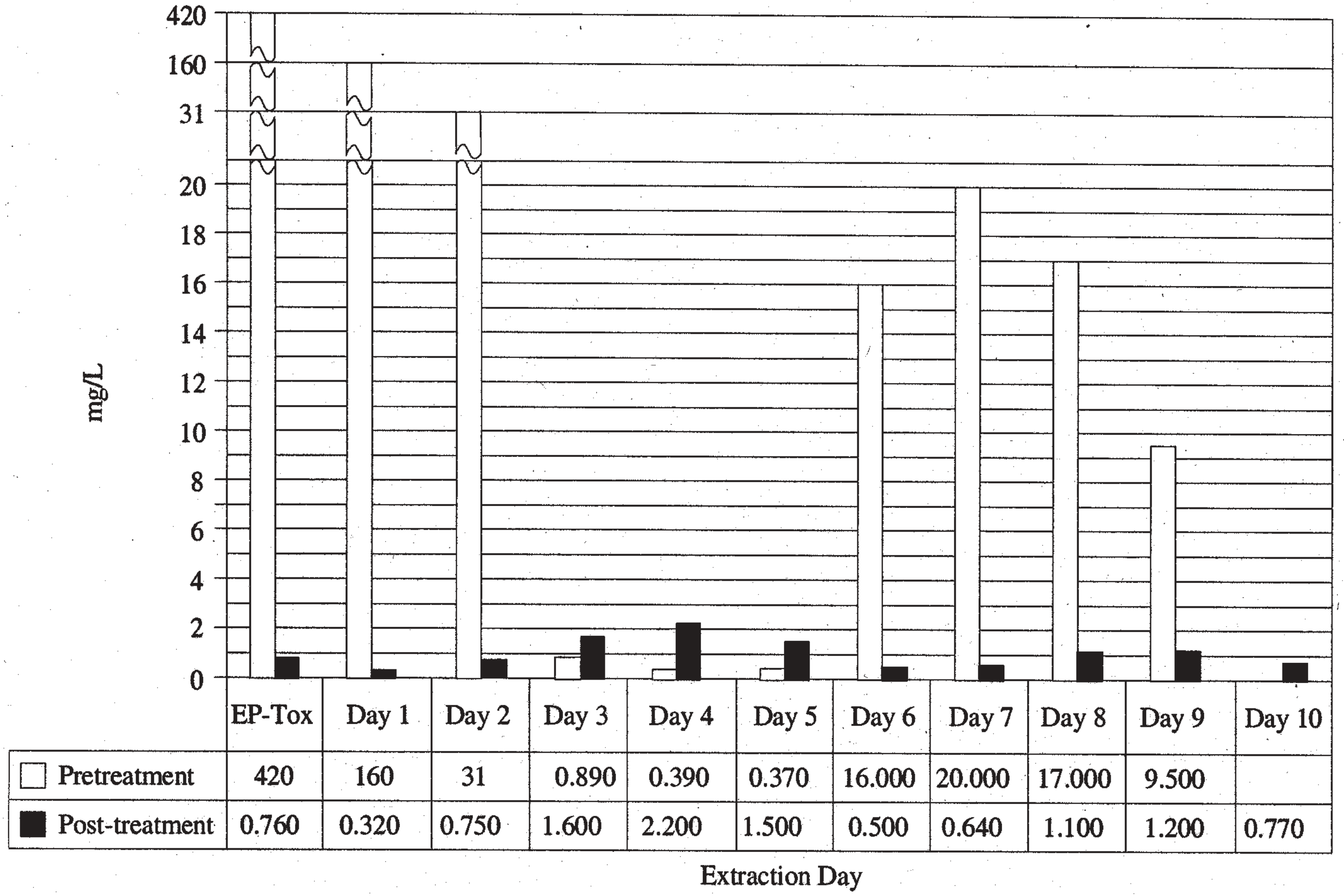
Lead Speciation by Sequential Extraction

This procedure uses sequential chemical extractions with different reagents to determine the concentration of lead that partitions into each of several discrete metal phases. The phases include exchangeable lead, lead bound to carbonates, lead bound to iron oxide, lead bound to manganese oxide, lead bound to organic matter, and residual lead.

The lead in the exchangeable phase, carbonates phase, iron oxide phase, manganese oxide phase, and organic matter phase is subject to release to the environment in a soluble form because of such changes in soil conditions as pH and Eh. The residual phase contains principally primary and secondary minerals that may hold the lead within their crystal structures. Therefore, long-term stability was evaluated by comparing the concentrations of lead in each phase of the untreated samples with the concentrations of lead in each phase of the treated samples. Long-term stability would be suggested if there are decreases in the concentrations of lead in the exchangeable phase, carbonates phase, iron oxide phase, manganese oxide phase, and organic matter phase, with an increase in the residual phase.

Tables 2-12 and Table 2-13 present the results of the sequential extractions on soil samples from the trailer park and the inactive pottery factory, respectively. On the basis of an assessment of graphical data distribution the sequential extraction data appear to be distributed normally. Therefore, the data on untreated soils from the trailer park and the inactive pottery factory were analyzed separately through application of a series of individual t-tests extraction.

Table 2-14 displays the summary statistics associated with the sequential extraction data from both locations. Those statistics include the estimated means for the untreated and treated soils, the calculated percent change in those means, and the level of significance of each t-score. Note that, because a total of six simultaneous t-tests were performed, a Bonferroni correction was used to preserve the overall Type 1 error rate. Therefore, no t-score should be considered statistically significant at the 0.05 level unless



	EP-Tox	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
☐ Pretreatment	420	160	31	0.890	0.390	0.370	16.000	20.000	17.000	9.500	
■ Post-treatment	0.760	0.320	0.750	1.600	2.200	1.500	0.500	0.640	1.100	1.200	0.770

Figure 2-4. MEP lead results for inactive pottery factory sampling Location 2.

the corresponding level of significance is less than 0.05/6 = 0.0083.

As Table 2-14 shows, the results of the sequential serial soil extractions indicate significant reductions in the concentrations of five of the six lead phases (exchangeable, carbonate, manganese oxide, iron oxide, and organic matter) and a significant increase in the residual lead phase in soils from both sites. Those results are consistent with those obtained for lead speciation by the SEM procedure (presented in the previous section).

Therefore, the lead speciation results were unanimously consistent with the attainment of objective S1; and thus it appears that those results suggest that Envirobond™ can enhance the long-term stability of treated soil.

Eh

Eh was evaluated to determine whether the treated soil exhibits an oxidizing or reducing environment. Reducing conditions favor retention of lead in the soil, which may increase the long-term stability of the treated soil. The long-term stability of the treated soil was evaluated by comparing the Eh values for untreated soil with the values for treated soils and by determining whether the soil exhibited an oxidizing or reducing environment. A decrease in the Eh values would suggest long-term stability of the treated soil.

Table 2-15 presents the Eh data for untreated and treated soil from the trailer park, and Table 2-16 presents the Eh data for untreated and treated soil from the inactive pottery factory. These Eh data appear to be normally distributed, based on a graphical data distribution assessment.

Table 2-17 presents the summary statistics associated with the analysis. Included in that table are the observed Eh means for untreated and treated soils, the estimated mean differences, and the levels of significance of the corresponding t-scores for the soil from the trailer park. The differences in the Eh mean levels from the untreated to the treated soil at both locations do not appear to be statistically significant. Overall, the results suggest that the application of Envirobond™ does not increase or decrease the Eh of the treated soil significantly. Therefore, the results for Eh did not demonstrate accomplishment of S1; however, it appears that failure to achieve that objective may

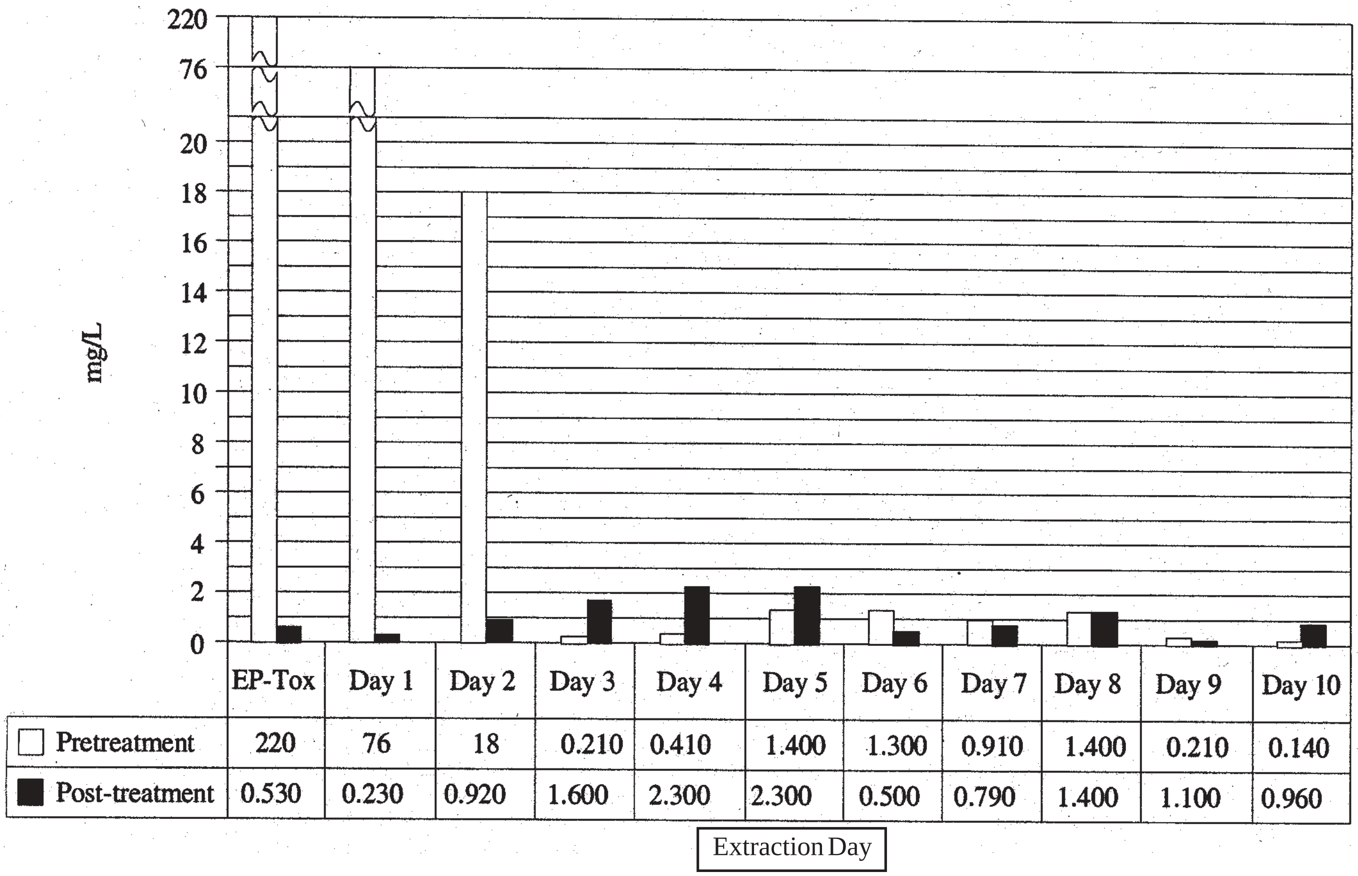


Figure 2-5. MEP lead results for inactive pottery factory sampling Location 3.

not reduce significantly the long-term stability of soils treated with Envirobond™.

pH

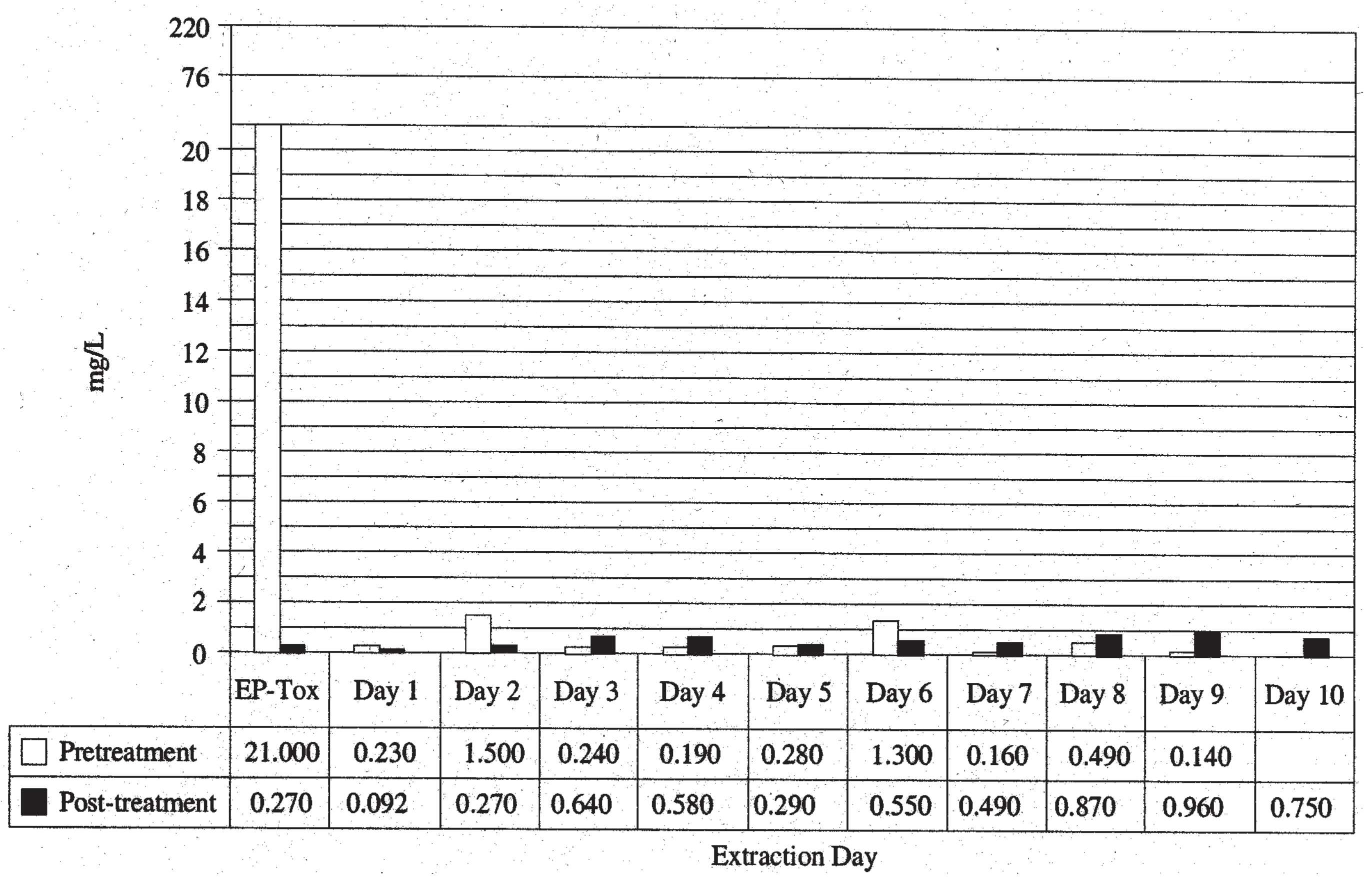
In general, the maximum retention of lead is achieved in soils that are characterized by a pH higher than 7.0, and the solubility of lead is generally lower in soils that have a pH between 7.0 and 10.0. Therefore, the pH values of untreated and treated soils were evaluated to determine whether the pH was higher than 7.0 in the samples of treated soil and to determine whether the pH values had increased after treatment with Envirobond™.

Table 2-18 presents the analytical results for pH in the soil from the trailer park. Table 2-19 displays the pH analytical results for pH in the soil from the inactive pottery factory. On the basis of an assessment of data distribution, the pH data appear to be distributed normally; however, pH is the negative log of hydrogen ion activity. Therefore, pH data on the untreated and the treated soils were converted to molar concentration units, and then were analyzed separately for the trailer park and the inactive pottery factory, through the use of individual t-tests.

Table 2-20 shows the summary statistics associated with the analysis. Included in the table are the observed pH means (calculated using observed pH values after they were converted to molar concentrations) for untreated and treated soils, the estimated mean differences, and the levels of significance of corresponding t-scores. Note that the increase in pH mean levels from untreated to treated soils at the trailer park appears to be statistically significant. However, the decrease in pH mean levels from untreated to treated soils at the inactive pottery factory also appears to be statistically significant, and none of the pH values for treated soils from either location are within the optimum range of 7.0 to 10.0. On the basis of those results, the application of Envirobond™ does not appear to have enhanced the long-term stability of the treated soil.

Cation Exchange Capacity

The objective of the tests for CEC was to determine if Envirobond™ could increase the CEC, which would indicate an increase in the ability of the soil to prevent migration of lead. The analytical results for CEC from one untreated soil sample were compared with those from one treated soil sample collected at both the trailer park and the inactive pottery factory to determine whether the cations in Envirobond™ changed the mobility of the lead in



	EP-Tox	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
☐ Pretreatment	21.000	0.230	1.500	0.240	0.190	0.280	1.300	0.160	0.490	0.140	
■ Post-treatment	0.270	0.092	0.270	0.640	0.580	0.290	0.550	0.490	0.870	0.960	0.750

Figure 2-6. MEP lead results for inactive pottery factory sampling Location 4.

the soil. Table 2-21 displays the CEC data from the trailer park, and Table 2-22 displays the CEC data from the inactive pottery factory. The CEC data for the trailer park show an increase from the result for untreated soil of 0.13 meq/g to the result for treated soil of 0.75 meq/g. CEC data for the inactive pottery factory also show an increase in the CEC from the result for untreated soil of 0.07 meq/g to the result for treated soil of 0.51 meq/g.

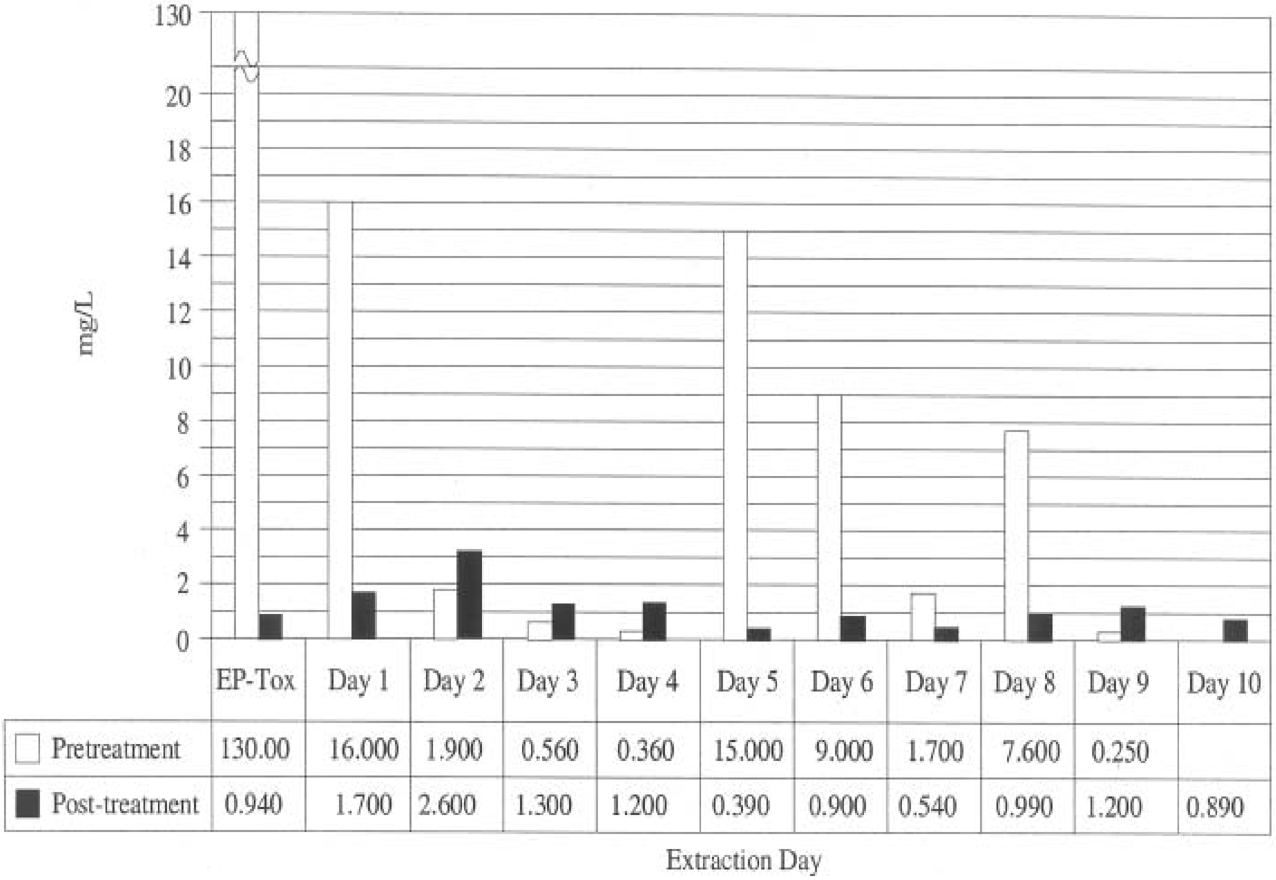
At both sites, the availability of exchangeable potassium showed the largest increase. The total observed increases in the available cations would be expected to reduce the migration rates and the total distances of migration of the total masses of lead in the soils at both sites. Therefore, improvements in the CEC indicate that the application of Envirobond™ appears to have enhanced the long-term stability of the treated soil. However, the results are not quantitative because CEC tests were conducted on only one sample from each site.

Acid Neutralization Capacity

One soil sample was collected before and another after the application of Envirobond™ at the trailer park and the inactive pottery factory; all four samples were analyzed for acid neutralization capacity. Increasing the acid neutralization capacity provides more ligands for formation of the more stable lead complexes, thereby enhancing the long-term stability of treated soil. Data on acid neutralization capacity for soil from the trailer park indicate that there was an increase from the result for untreated soil of 0.0242 meq/g to the result for treated soils of 1.0580 meq/g. The data on acid neutralization capacity for the inactive pottery factory indicate that there was a decrease from the data on the result for untreated soil of 0.6266 meq/g to the result for treated soil of 0.4408 meq/g. Because the analytical results were not consistent at the two sites, the data do not suggest that the long-term stability of the treated soil was enhanced by the application of Envirobond™. However, the results are not statistically conclusive because only one pair of soil samples was collected at each location.

Total Lead in Soil

Two analytical procedures were used to determine total concentrations of lead in the soil. One procedure, SW-846 Method 3050B, uses a nitric acid solution to digest the lead. The solution is a very strong acid that dissolves almost all of lead in a sample that could become "environmentally available" (EPA 1996); however, the method is not a total digestion technique. Lead bound in silicates and lead



	EP-Tox	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
☐ Pretreatment	130.00	16.000	1.900	0.560	0.360	15.000	9.000	1.700	7.600	0.250	
■ Post-treatment	0.940	1.700	2.600	1.300	1.200	0.390	0.900	0.540	0.990	1.200	0.890

Figure 2-7. MEP lead results for inactive pottery factory sampling Location 5.

bound to organics may not be dissolved by this method. Therefore, a portion of each soil sample was also digested by hydrofluoric acid. That procedure digests the siliceous and organic matrices and other complex matrices to produce a total concentration of lead.

Application of both procedures to determining the concentration of lead was used to ascertain whether Soil Rescue forms complex matrices that are not dissolved readily. Binding of the lead into complex matrices should reduce the concentration of lead that is environmentally available. If the concentration of lead determined by nitric acid digestion decreases after treatment while the concentration of lead determined by hydrofluoric acid digestion does not change significantly, the risk of exposure to environmentally available lead is reduced. If the concentration of lead determined by nitric acid digestion increases after treatment while the concentration of lead determined by hydrofluoric acid digestion does not change significantly, the risk of exposure to environmentally available lead is increased. If the concentration of lead determined by both procedures does not change significantly, the risk of exposure to environmentally available lead is unchanged. However, if the concentration of lead determined by hydrofluoric acid digestion increases significantly, the distribution of lead in complex matrices may follow a non-normal pattern. These tests were extremely aggressive tests, thus meeting the acceptance criteria established for these tests was not as important as meeting the acceptance criteria of other tests involving long-term chemical stability.

Table 2-23 lists the concentrations of lead determined by nitric acid digestion of untreated and treated soil from the trailer park, and Table 2-24 lists the concentrations of lead acid digestion of untreated and treated soil from the inactive pottery factory. The data appear to be distributed normally, as indicated by a graphical assessment of data distribution. Therefore, the differences between total lead in treated and untreated soils were analyzed separately for the trailer park and the inactive pottery factory, through the use of separate Student t-tests.

Table 2-25 displays the summary statistics associated with the analysis. The statistics include the estimated untreated and treated mean concentrations of lead, the calculated percent change in the means, and the levels of significance of the t-scores. The observed mean concentration of lead in soil from the trailer park decreased from 1,157.9 mg/kg to 809.5 mg/kg, while the mean concentration of lead in soil from the inactive pottery factory decreased from 36,140 mg/kg to 30,488.9 mg/kg. The corresponding t-scores indicate that the decrease at the trailer park is statistically significant, and that the decrease at the inactive pottery factory is not statistically significant. Therefore, the statistical analysis of the data suggests that, at the trailer park, Envirobond™ has resulted in binding a portion of the to-

Table 2-11. Summary of Percent Frequency of Lead Phases Statistical Data

Phase of Lead	Untreated			Treated		
	Mean	Standard Deviation	Number of Zero Values	Mean	Standard Deviation	Number of Zero Values
Anglesite	0.01	nc	9	0	nc	10
Barite	0.18	.22	4	0.16	.3	6
Brass	0.48	nc	9	0.07	nc	9
Cerussite	0.87	nc	8	0.04	nc	9
Clay	0.06	nc	9	0	nc	10
Fe-Oxide[2]	29.55	23.35	1	4.34	2.43	2
Fe-Pb Sulfate	0.44	1.14	2	0.19	0.6	1
Galena	0.01	nc	9	0	nc	10
Glass[2]	45.74	19.73	0	14.37	5.55	0
Mn-Oxide	7.09	nc	5	0.22	nc	5
Organic	1.05	nc	8	1.68	nc	7
Pb Vanadate	0	nc	10	0	nc	10
PbMO	2.71	3.46	1	0.31	0.19	0
$PbSiO_2$	0.26	nc	7	0.03	nc	9
Phosphate	0.05	nc	8	2.3	nc	5
Si-Phosphate[2]	0	0	10	76.95	5.24	0
Slag[2]	11.96	11.02	1	0	0	10
Solder	0.04	nc	9	0	nc	10

[1] nc = not calculated. Standard deviations were not calculated for data on lead phases that were associated with five or more zero-value data points for both the untreated and treated soils.

[2] Appears to be a significant difference between treated and untreated soils.

tal lead in such a manner that it is no longer subject to digestion using nitric acid (This suggestion, however is not supported by the results of the hydrofluoric acid digestion method for total lead; see next section). However there were no significant differences in mean concentrations of total lead between untreated and treated soils from the inactive pottery factory using the nitric acid digestion method for total lead.

Table 2-26 presents the concentrations of lead determined by hydrofluoric acid digestion of untreated and treated soil from the trailer park, and Table 2-27 presents the concentrations of lead determined by hydrofluoric acid digestion of untreated and treated soils from the inactive pottery factory. The data also appear to be distributed normally, and the estimates of sample variance for the data from both locations again appear to be approximately equivalent. Therefore, separate Student t-tests were performed on the data from the pottery factory and the data from the trailer park to compare the differences in total concentrations of lead in untreated and treated soils.

Table 2-28 displays the summary statistics associated with the analyses. The statistics again include the estimated mean concentrations of lead for untreated and treated soil, the calculated percent change in the means, and the level of significance of the t-scores. The observed mean concentration of lead in soil from the trailer park decreased from 1,345.7 mg/kg to 666.8 mg/kg, and the mean concentration of lead in soil from the pottery factory also decreased from 41,500 mg/kg to 28,633 mg/kg. The change in the mean concentrations of lead is not statistically significant at the inactive pottery factory, according to the t-score value, which is the expected outcome of the analysis. However, the decrease in total concentrations of lead at the trailer park is considered significant. Therefore, the statistical analysis of those data suggests that there was no difference in concentrations of lead between treated and

Table 2-12. Sequential Serial Soil Extracts Results from the Trailer Park

		Untreated						Treated					
Unit	Sampling Location	1	2	3	4	5	6	1	2	3	4	5	6
A	Comp	5.89	5.02	2.987	4.77	6.44	228	0.48	0.15	0.018	0.51	1.62	607
B	Comp	2.86	2.37	1.445	4.11	3.16	169	0.02	0.05	0.016	0.12	0.59	307
D	Comp	37.14	40.08	10.85	32.76	32.05	862	1.67	2.64	1.167	2.19	17.74	3128
E	Comp	31.45	60.78	18.82	32.22	25.13	554	1.25	1.57	0.319	1.66	11.13	3004
F	Comp	29.26	87.24	4.182	51.90	52.20	1182	2.07	1.95	0.640	0.84	11.40	2941
H	Comp	23.65	12.39	10.867	24.40	53.44	1698	0.72	1.16	0.146	0.56	3.74	1620
I	Comp	10.95	8.16	1.723	6.95	7.65	194	0.22	0.31	0.067	0.76	2.75	513
J	Comp	12.17	15.21	3.158	12.76	10.69	253	0.13	0.45	0.083	0.47	4.54	851
P	Comp	10.67	28.07	6.903	18.48	15.11	684	0.85	0.76	0.276	0.86	3.48	1362
S	Comp	11.44	12.99	1.748	12.59	7.92	497	0.68	1.07	0.02	0.66	4.02	1191

Note: 1 = Exchangeable phase (mg/L Pb), 2 = Carbonate phase (mg/L Pb), 3 = Manganese oxide phase (mg/L Pb), 4 = Iron oxide phase (mg/L Pb), 5 = Organic matter phase (mg/L Pb), 6 = Residual phases (mg/L Pb).

Table 2-13. Sequential Serial Soil Extracts Results from the Inactive Pottery Factory

		Untreated						Treated					
Unit	Sampling Location	1	2	3	4	5	6	1	2	3	4	5	6
V	1	178.40	1,460.6	169.60	657.00	162.40	20,948.	41.58	96.85	4.81	98.98	1,084.	33,788
V	2	171.20	2,122.7	327.95	718.20	158.10	14,034.	43.74	45.02	4.67	58.88	565.60	25,213
V	3	135.50	740.83	155.73	352.20	157.70	13,872.	25.47	10.95	5.70	105.00	1,056.	23,931
V	4	159.20	791.60	125.60	362.80	171.50	13,273.	31.23	65.48	4.03	56.76	726.10	26,056
V	5	141.80	1,003.5	168.58	598.20	185.20	20,748.	49.64	57.95	3.81	76.69	850.40	27,664
V	6	n/s	n/s	n/s	n/s	n/s	n/s	23.26	87.32	4.18	96.44	992.40	31,917
V	7	n/s	n/s	n/s	n/s	n/s	n/s	54.44	50.79	5.77	51.60	766.10	27,162
V	8	n/s	n/s	n/s	n/s	n/s	n/s	25.21	109.70	5.13	109.20	896.30	27,208
V	9	n/s	n/s	n/s	n/s	n/s	n/s	50.79	49.93	2.50	69.95	792.00	27,071

Note: 1 = Exchangeable phase (mg/L Pb); 2 = Carbonate phase (mg/L Pb); 3 = Manganese oxide phase (mg/L Pb); 4 = Iron oxide phase (mg/L Pb), 5 = Organic matter phase (mg/L Pb); 6 = Residual phases (mg/L Pb); n/s = not sampled.

Table 2-14. Sequential Serial Soil Extracts: Summary Statistics

Phase	Untreated Mean (mg/L Pb)	Treated Mean (mg/L Pb)	Mean Difference (Untreated - Treated)	Significance level
Trailer Park				
Exchangeable	17.55	0.81	16.74	0.0005[1]
Carbonate	27.23	1.01	26.22	0.007[1]
Manganese Oxide	6.27	0.27	6	0.004[1]
Iron Oxide	20.09	0.86	19.23	0.001[1]
Organic Matter	21.38	6.1	15.28	0.008[1]
Residual	632.1	1,552.4	-920.3	0.005[1]
Inactive Pottery Factory				
Exchangeable	157.26	38.37	118.89	0.0001[1]
Carbonate	1223.9	74.45	1,149.45	0.005[1]
Manganese Oxide	189.49	4.51	184.98	0.003[1]
Iron Oxide	537.8	80.40	457.4	0.002[1]
Organic Matter	167	858.98	-691.98	0.0001[1]
Residual	16,575	27,779	-11,204	0.0005[1]

[1] Significant difference between treated and untreated soil (A significance level of 0.0083 or lower is needed to declare a significant difference, based on a Bonferroni correction needed to preserve the significance level of 0.05)
Note: Hypothesis associated with significance level is H_o: mean untreated - mean treated = 0.

Table 2-15. Trailer Park Eh Analytical Results

Experimental Unit	Sampling Location	Untreated Eh (mV)	Treated Eh (mV)
A	Composite	660	560
B	Composite	560	650
D	Composite	550	560
E	Composite	730	560
F	Composite	640	450
H	Composite	530	760
I	Composite	530	1200
J	Composite	580	810
P	Composite	510	550
S	Composite	630	580

Table 2-16. Inactive Pottery Factory Eh Analytical Results

Experimental Unit	Sampling Location	Untreated Eh (mV)	Treated Eh (mV)
V	1	610	530
V	2	510	530
V	3	520	530
V	4	530	650
V	5	570	550
V	6	n/s	560
V	7	n/s	460
V	8	n/s	630
V	9	n/s	640

Note: n/s = not sampled.

Table 2-17. Eh Summary Statistics

Statistic	Trailer Park Data (mV)	Inactive Pottery Factory Data (mV)
Untreated Mean (Standard deviation)	592 (70.5)	548 (41.5)
Treated Mean (Standard deviation)	668 (215)	562 (65)
Mean Difference (Untreated - Treated)	76	-14
Significance level	0.185	0.3136

Note: Hypothesis associated with significance level is H_o: mean untreated - mean treated = 0. A paired t-test was conducted on data from the trailer park, and an unpaired t-test assuming unequal variances between treated and untreated samples was conducted on the data from the pottery factory.

Table 2-18. Trailer Park pH Analytical Results

Experimental Unit	Sampling Location	Untreated	Treated
A	Composite	5.2	6.6
B	Composite	5.2	6.5
D	Composite	6.1	6.3
E	Composite	6.2	6.4
F	Composite	7.0	5.9
H	Composite	5.8	6.0
I	Composite	5.4	6.9
J	Composite	6.0	6.6
P	Composite	6.0	6.1
S	Composite	5.7	6.2

untreated soils from the inactive pottery factory and a significant decrease in mean concentration of lead in treated soil from the trailer park, as determined by hydrofluoric acid digestion method. The reason for the significant decrease is unknown; however, it is possible that the drop in total lead concentrations (as measured by the hydrofluoric acid digestion method) at the trailer park may have been the result of the sampling efforts conducted on the untreated soils, which may have removed some hot spots of high lead concentrations that were bound in stable matrices (therefore, no more of such materials may have remained when the soils were sampled after the application of Envirobond™). Therefore, the decrease in lead between the untreated and treated soils observed in the results of the nitric acid digestion method at the trailer park also may be due to the removal of hot spots, rather than the binding action of Envirobond™.

SPLP Lead

The SPLP concentrations of lead in untreated soil were compared with the SPLP concentrations of lead in treated soil to determine whether the application of Envirobond™ decreased the solubility of the lead in the soil. The criterion selected for determining whether the application of Envirobond™ had an effect on the soil was a concentration of SPLP lead in treated soil of less than 5.0 mg/L.

Table 2-19. Inactive Pottery Factory pH Analytical Results

Experimental Unit	Sampling Location	Untreated	Treated
V	1	7.2	5.8
V	2	7.7	5.7
V	3	7.7	6.2
V	4	7.3	4.8
V	5	7.3	5.8
V	6	n/s	6.3
V	7	n/s	4.6
V	8	n/s	6.3
V	9	n/s	5.5

Note: n/s = Not sampled

Table 2-20. pH Summary Statistics

Statistic	Trailer Park Data	Inactive Pottery Factory Data
Untreated Mean[1]	5.62	7.36
Treated Mean[1]	6.26	5.25
Mean Difference (Untreated - Treated)	0.64	-2.11
Significance level	0.018	0.045

1. Mean values are reported as pH; however, they were calculated based on molar concentration units obtained by conversion of the individual pH unit measurements shown in tables 2-18 and 2-19.

Note: Hypothesis associated with significance level is H_o: mean untreated - mean treated = 0. A paired t-test was conducted on data from the trailer park, and an unpaired t-test assuming unequal variances between treated and untreated samples was conducted on the data from the pottery factory.

Table 2-21. CEC Analytical Results for Soil from the Trailer Park

Untreated/ Treated	Na (meq/g)	Al (meq/g)	Ca (meq/g)	Mg (meq/g)	K (meq/g)	Fe (meq/g)	Mn (meq/g)	Total (meq/g)
Untreated	0.0002	0.0004	0.1083	0.0185	0.0038	0.0001	0.0005	0.1316
Treated	0.6236	0.0001	0.0878	0.0338	0.0024	0.0000	0.0003	0.7480

Note: meq/g = milliequivalents per gram = weight of element in soil (mg) ÷ (atomic weight [g] ÷ valence) per gram of soil.

Table 2-22. CEC Analytical Results for Soil from the Inactive Pottery Factory

Untreated/ Treated	Na (meq/g)	Al (meq/g)	Ca (meq/g)	Mg (meq/g)	K (meq/g)	Fe (meq/g)	Mn (meq/g)	Total (meq/g)
Untreated	0.0024	0.0001	0.0606	0.0064	0.0003	0.0000	0.0000	0.0699
Treated	0.2961	0.0002	0.1310	0.0771	0.0037	0.0000	0.0032	0.5113

Note: meq/g = milliequivalents per gram = weight of element in soil (mg) x ÷ (atomic weight [g] ÷ valence) per gram of soil.

Table 2-23. Lead Analytical Results for Nitric Acid Digestion for Soil from the Trailer Park

Experimental Unit	Sampling Location	Untreated (mg/kg)	Treated (mg/kg)
A	Composite	399	506
B	Composite	251	175
D	Composite	2,230	1,900
E	Composite	2,130	1,390
F	Composite	2,520	1,570
H	Composite	1,130	575
I	Composite	511	307
J	Composite	704	473
P	Composite	1,070	758
S	Composite	634	441

Table 2-24. Lead Analytical Results for Nitric Acid Digestion for Soil from the Inactive Pottery Factory

Experimental Unit	Sampling Location	Untreated (mg/kg)	Treated (mg/kg)
V	1	36,600	56,500
V	2	36,300	23,100
V	3	22,800	26,300
V	4	27,500	23,200
V	5	57,500	28,700
V	6	n/s	27,200
V	7	n/s	27,800
V	8	n/s	39,500
V	9	n/s	22,100

Note: n/s = not sampled.

Table 2-25. Summary Statistics for Nitric Acid Digestion

Statistic	Trailer Park Data (mg/kg)	Inactive Pottery Factory Data (mg/kg)
Untreated mean (Standard deviation)	1,157.9 (834)	36,140.0 (13,314)
Treated mean (Standard deviation)	809.5 (592)	30,488.9 (11,038)
Mean Difference (Untreated - Treated)	348.4	5,651.0
Level of significance	0.003	0.223

Note: Hypothesis associated with significance level is H_o: mean untreated - mean treated = 0. A paired t-test was conducted on data from the trailer park, and an unpaired t-test assuming unequal variances between treated and untreated samples was conducted on the data from the pottery factory.

Table 2-26. Trailer Park Lead Analytical Results Using Hydrofluoric Acid Digestion

Experimental Unit	Sampling Location	Untreated (mg/kg)	Treated (mg/kg)
A	Composite	214	453
B	Composite	307	226
D	Composite	2,770	522
E	Composite	2,390	228
F	Composite	2,780	1,950
H	Composite	1,230	939
I	Composite	492	382
J	Composite	664	508
P	Composite	1,220	937
S	Composite	1,390	523

Table 2-27. Inactive Pottery Factory Lead Analytical Results Using Hydrofluoric Acid Digestion

Experimental Unit	Sampling Location	Untreated (mg/kg)	Treated (mg/kg)
V	1	54,900	26,600
V	2	53,200	22,400
V	3	11,500	27,700
V	4	40,900	18,200
V	5	47,000	32,000
V	6	n/s	35,000
V	7	n/s	29,300
V	8	n/s	31,600
V	9	n/s	34,900

Note: n/s = not sampled.

Table 2-28. Summary Statistics for Hydrofluoric Acid Digestion

Statistic	Trailer Park Data (mg/kg)	Inactive Pottery Factory Data (mg/kg)
Untreated Mean (Standard deviation)	1,345.7 (987)	41,500 (17,657)
Treated Mean (Standard deviation)	666.8 (514)	28,633 (5,625)
Mean Difference (Untreated - Treated)	678.9	12,032
Significance level	0.02	0.0904

Note: Hypothesis associated with significance level is H_o: mean untreated - mean treated = 0. A paired t-test was conducted on data from the trailer park, and an unpaired t-test assuming unequal variances between treated and untreated samples was conducted on the data from the pottery factory.

Table 2-29 lists the concentrations of SPLP lead in untreated and treated soil from the trailer park. The concentrations of SPLP lead in untreated soil from the trailer park all were lower than the detection limit of 0.5 mg/L. Of the 10 samples of treated soil from the trailer park, 7 contained concentrations of SPLP lead that were higher than the detection limit, but none of those concentrations exceeded the criterion of 5.0 mg/L. The concentrations of SPLP lead in untreated soil from the trailer park indicate that the contaminated soil would not require treatment.

Table 2-30 lists the concentrations of SPLP lead in untreated and treated soil from the inactive pottery factory. The concentrations of SPLP lead in untreated soil from the inactive pottery factory all were lower than the detection limit of 0.5 mg/L. Of the 9 samples of treated soil from the inactive pottery factory, 7 contained concentrations of SPLP lead that were higher than the detection limit, but none of those concentrations exceeded the criterion of 5.0 mg/L. The concentrations of SPLP lead in untreated soil from the inactive pottery factory indicate that the contaminated soil would not require treatment. A parametric statistical analysis of the concentrations of SPLP lead in treated soil cannot be performed because of excessive number of nondetects. However, the following nonparametric argument can be made to support a conclusion that the mean concentration of SPLP lead in treated soil does not exceed 5.0 mg/L. If the mean was greater than or equal to 5.0 mg/L, the probability of observing an individual concentration of SPLP lead higher than 5.0 mg/L would be at least 0.5. Therefore, the probability of observing 10 independent samples of treated soil (9 samples at the inactive pottery factory) at less than 5.0 mg/L could be no more than $0.5^{10} = 0.00098$ ($0.5^9 = 0.001953$ at the inactive pottery factory) . Therefore, the hypothesis that the mean concentration of SPLP lead in treated soil from the trailer park exceeds 5.0 mg/L is rejected at a 0.001 level of significance at the trailer park and at a 0.01 level of significance at the inactive pottery factory. The statistical analysis of untreated and treated soil from the trailer park and the inactive pottery factory did not indicate a statistically significant change in concentrations of SPLP lead.

Phosphates

Envirobond™ contains phosphoryl esters used to form metal complexes. Phosphates may be released from the soil into local streams through stormwater runoff. Therefore, two analytical procedures were used to evaluate whether the phosphates in Envirobond™ could be released into the environment. The methods are comparison of the total phosphate concentrations in untreated and treated soils at both sites by SW-846 Method 9056 and comparison of the concentrations of untreated and treated soils that leach from untreated and treated soil when the SPLP test (SW-846 Method 1312) is applied and analysis of the extract for total phosphates by SW-846 Method 9056.

Table 2-31 lists the total concentrations of phosphate for soil from the trailer park, and Table 2-32 lists the total concentrations of phosphates for soil from the inactive pottery factory. The data from both sites clearly show significant increases in the concentrations of phosphates after the application of Envirobond™.

Table 2-33 lists the concentrations of SPLP phosphates for untreated and treated soils from the trailer park, and Table 2-34 lists the concentrations of SPLP phosphates for untreated and treated soil from the inactive pottery factory. The data from both sites also clearly show a significant increase in the concentrations of SPLP phosphates after the application of Envirobond™.

Table 2-29. SPLP Lead Analytical Results for Soil from the Trailer Park

Experimental Unit	Sampling Location	Untreated (mg/L)	Treated (mg/L)
A	Composite	<0.50	<0.50
B	Composite	<0.50	<0.50
D	Composite	<0.50	1.7
E	Composite	<0.50	3.3
F	Composite	<0.50	2.3
H	Composite	<0.50	0.85
I	Composite	<0.50	0.80
J	Composite	<0.50	0.52
P	Composite	<0.50	1.8
S	Composite	<0.50	<0.50

Table 2-30. SPLP Lead Analytical Results for Soil from the Inactive Pottery Factory

Experimental Unit	Sampling Location	Untreated (mg/L)	Treated (mg/L)
V	1	<0.50	1.4
V	2	<0.50	1.1
V	3	<0.50	1.4
V	4	<0.50	<0.50
V	5	<0.50	0.83
V	6	n/s	1.6
V	7	n/s	<0.50
V	8	n/s	1.2
V	9	n/s	0.65

Note: n/s = not sampled.

Table 2-35 displays the estimated means and 95 percent confidence intervals for both sets of data on treated soil from both sites. The estimated mean concentrations of phosphates were 6,575 mg/kg for the trailer park and 8,085.5 mg/kg for the inactive pottery factory. The estimated mean concentrations of SPLP phosphates were 450.5 mg/L and 322 mg/L for the the trailer park and inactive pottery factory, respectively. On the basis of the data obtained by conducting analytical procedures, it appears that phosphates from the application of Envirobond™ could leach from the soil, a circumstance that could affect nearby surface water.

Summary

In total, 11 types of analytical procedures were conducted to predict the long-term stability of the soil treated by Envirobond™. The results for each procedure for both the trailer park and the inactive pottery factory were presented in the preceding subsections and are summarized in the table titled "Summary of Results for Objective S1".

The results of conducting most of the procedures indicate that Envirobond™ appears to increase long-term stability. However, the results of some of the procedures suggest that Envirobond™ does not increase long-term stability. Long-term stability of soil was indicated for soils treated by Envirobond™ at both test locations, as shown by the analytical results of the MEP, lead speciation by sequential extraction, CEC, and SPLP lead test procedures. In addition, long-term stability of the soil was indicated at one site, but not at the other, by analytical results of the acid neutralization capacity test. The analytical results or testing by the lead speciation by SEM (conducted only on soils from the trailer park) were mixed in that the silica phosphate phase (low solubility) was increased and some soluble species of lead were reduced, while other stable phases of lead were also reduced. For both locations, long-term stability of soil was not indicated for soils treated by Envirobond™ by the results of the pH analyses, Eh analyses, separate analyses for total lead by nitric and hydrofluoric acids, total phosphates, and SPLP phosphates.

2.4.4 Evaluation of S2

Demonstrate that the application of Envirobond™ does not increase the public health risk of exposure to lead.

During the demonstration, it was necessary to remove vegetation with a sod cutter and to prepare the soil for the collection of samples before and after treatment. The activities generated dust that was monitored with real-time devices. Air sampling devices were used to determine the total concentrations of lead in the dust. Accomplishment of S2 was evaluated by collecting air samples through filters during tilling operations and calculating the exposure to lead on the basis of total lead content of the air sampling filters and the length of exposure. The concentration of lead was determined by the nitric acid digestion method described in Section 2.3.1. The exposure calculated was compared with NAAQS for lead, which currently is 1.5 μm/m^3 of air, averaged over a period of three consecutive months. Table 2-36 lists the exposures calculated for the worker during the demonstration.

The only sample result in the detectable range, 24 g/m^3, occurred on September 25, 1998 on the east area sample. The tilling activity at this plot and the corresponding sampling period were 5 minutes in duration. These values extrapolate to a concentration of 9.3 x 10^{-4} mg/m^3 over a 3-month period, which is lower than the NAAQS standard. Assuming that the concentration was to remain constant during extended remediation activities; however, the NAAQS standard would be exceeded after approximately

Table 2-31. Total Phosphates Analytical Results for Soil from the Trailer Park

Experimental Unit	Sampling Location	Untreated (mg/kg)	Treated (mg/kg)
A	Composite	<12.3	2350
B	Composite	<12.8	6050
D	Composite	<11.5	6250
E	Composite	<12.8	5950
F	Composite	<12.7	12000
H	Composite	<12.0	5550
I	Composite	<12.7	4380
J	Composite	<12.1	6480
P	Composite	<12.3	6510

Table 2-32. Total Phosphates Analytical Results for Soil from the Inactive Pottery Factory

Experimental Unit	Sampling Location	Untreated (mg/kg)	Treated (mg/kg)
V	1	<13.3	5,680
V	2	<12.6	7,810
V	3	<13.6	3,930
V	4	<13.6	13,000
V	5	<13.8	9,220
V	6	n/s	5,490
V	7	n/s	15,000
V	8	n/s	4,660
V	9	n/s	7,980

Note: n/s = Not sampled

Table 2-33. SPLP Phosphates Analytical Results for Soil from the Trailer Park

Experimental Unit	Sampling Location	Untreated (mg/L)	Treated (mg/L)
A	Composite	<1.0	264
B	Composite	<1.0	409
D	Composite	<1.0	324
E	Composite	<1.0	459
F	Composite	<1.0	723
H	Composite	<1.0	496
I	Composite	<1.0	310
J	Composite	<1.0	352
P	Composite	<1.0	509
S	Composite	<1.0	639

Table 2-34. SPLP Phosphates Analytical Results for Soil from the Inactive Pottery Factory

Experimental Unit	Sampling Location	Untreated (mg/L)	Treated (mg/L)
V	1	<1.0	249
V	2	<1.0	296
V	3	<1.0	171
V	4	<1.0	516
V	5	<1.0	327
V	6	n/s	213
V	7	n/s	613
V	8	n/s	203
V	9	n/s	310

Note: n/s = not sampled.

135 hours. The application of Envirobond™ does not appear to create a significant quantity of dust; however, air monitoring was not conducted during that activity. If it is determined that it is necessary to remove the soil or use other techniques that may generate dust, air monitoring with real-time devices correlated to actual concentrations of lead in the air (for example, high-volume air samplers) and, if appropriate, dust suppression measures should be employed.

2.4.5 Evaluation of Objective S3

Document baseline geophysical and chemical conditions of the soil before the addition of Envirobond™.

Soil samples collected from the locations at the trailer park and the inactive pottery factory at which the demonstration was conducted were analyzed to determine the soil classification and to determine whether VOCs, SVOCs, or oil and grease were present in the soils.

One soil sample from each of the demonstration sites was analyzed by ASTM Method D 2487-93, Standard Classification of Soils for Engineering Purposes, to determine the soil classification. The soil type for both sites has been identified as sandy silt, an organic clay having low plastic limits and liquid limits of less than 50 percent.

Table 2-35. Phosphate Summary Statistics

Location	Data	Mean	95% Confidence Interval
Trailer Park	Total phosphates (mg/kg)	6,575	(5,192—7,958)
	SPLP phosphates (mg/L)	450.8	(361–541)
Inactive Pottery Factory	Total phosphates (mg/kg)	8,085.5	(5,610—10,561)
	SPLP phosphates (mg/L)	322	(225—419)

The results of analysis for VOCs did not indicate the presence of any VOCs in the soils at either site. The analysis for SVOCs indicated the presence of the following SVOCs in the soils at the inactive pottery factory: benzo(a)anthracene (0.82 mg/kg), benzo(b)fluoranthene (0.91 mg/kg), benzo(k)fluoranthene (0.77 mg/kg), benzo(a)pyrene (0.69 mg/kg), chrysene (1.0 mg/kg), fluoranthene (1.9 mg/kg), and pyrene (1.9 mg/kg). Those SVOCs typically are found in crude oil, fuel oil, or used motor oil. The soil in that area did show signs of staining that may have been the result of the disposal of a small quantity of waste oil. On the basis of the concentrations detected and the current state regulations governing petroleum releases, it does not appear that the SVOCs present at the site require remediation. The technology developer indicated that the SVOC would not interfere with Envirobond™. The analytical results for the soil at the inactive pottery factory indicated that oil and grease were present at a concentration of 3,680 mg/kg. The analytical results for the soil at the trailer park did not indicate that oil and grease were present.

Humic and Fulvic Acids

The soil humus fractions (humic acid and fulvic acid) were determined from untreated samples collected from both sites. Humus in soils contributes ligands that can bind with the lead. These concentrations can be used to evaluate whether the humus is contributing to the concentration of the lead species bound to organic fractions. That information is important when a technology uses humic acids to bind the lead. However, since Envirobond™ does not use humic acids to bind the lead, the concentration of humic acids is provided only as a description of the organic matter in the soil. The concentration of humic acid in the soil at the trailer park was 2,400 mg/L, and the concentration of humic acid in the soil at the inactive pottery factory was 1,400 mg/L. The concentration of fulvic acid in the soil at the trailer park was 600 mg/L, and the concentration of fulvic acid at the inactive pottery factory was less than 500 mg/L.

2.4.6 Evaluation of Objective S4

Document the operating and design parameters of Envirobond™.

On the basis of information obtained through the SITE evaluation, from RMRS, and from other sources, an economic analysis examined 12 cost categories for a scenario in which Envirobond™ was applied at full scale to treat soil contaminated with lead at a Superfund site. For the cost estimate, it was assumed that the site was one acre in size and that the treatment was applied to a depth of 6 inches, or approximately 807 cubic yards of soil. The estimate assumed that the soil characteristics and lead concentrations of lead at the site were the same as those encountered during the CRPAC evaluation. With those assumptions, the total costs were estimated to be $32,500 per acre or $40.27 per yd$^{3.}$ Costs for application of Envirobond™ may vary significantly from that estimate, depending on site-specific factors.

2.5 Quality Control Results

The overall quality assurance (QA) objective for the SITE program demonstration, as set forth in the QAPP, was to produce well-documented data of known quality as measured by the precision, accuracy, completeness, representativeness, and comparability of the data, and the conformance of the data to the project required detection limits (PRDL) for the analytical methods. Specific QA objectives were established as benchmarks by which each of the criteria was to be evaluated. Section 3.0 of the QAPP presented the QA objectives for the critical parameters.

This section discusses the quality control (QC) data with respect to the QA objective of the project for critical parameters. The results, and those for noncritical parameters, can be found in the unpublished TER for this SITE demonstration (Tetra Tech 2001). The TER is available upon request from the EPA work assignment manager (see Section 1.4 for contact information).

QA objectives for laboratory analysis of the critical parameter bioavailable lead were evaluated on the basis of analytical results from matrix spike samples and matrix spike duplicate samples (MS/MSD), blank spikes, laboratory control samples (LCS), reagent blanks, bottle blanks, and calibration criteria. QA objectives for laboratory analysis of the critical parameter TCLP lead were evaluated on the basis of MS/MSDs, LCS/LCSD, and method blanks. Table 7-1 of the QAPP summarizes the internal acceptance criteria for laboratory QC samples, as well as corrective action procedures for the demonstration.

2.5.1 Completeness

The QA objective for data completeness specified by the QAPP is that 100 percent of all planned measurements will be obtained and will be valid. As discussed in Section 3.1, SITE Program personnel did not collect an equipment and field blank during the post-treatment sampling for bioavailable lead analysis. Analytical results of the pretreatment equipment and field blanks and subsequent long-term monitoring blanks did not indicate

Summary of Results for Objective S1

Procedure	Results	Interpretation	
		Trailer Park	Pottery Factory
MEP	All results met the acceptance criteria for S1 (see Table 2-4).	Envirobond™ exhibits long-term stability, as indicated by the results of this procedure.	
Lead speciation by SEM	Results for 4 of 18 phases of lead met the acceptance criteria for S1, and results for one phase did not meet the criteria. Results for the other 13 phases did not appear to be affected by the treatment.	Mixed: Lead in silica phosphates appears to increase, and lead in oxide phases appear to decrease after addition of Envirobond™; however, lead in glass and slag appears to decrease.	This procedure was not conducted on soils from this location.
Lead speciation by sequential extractions	Results for all six phases of lead at both sites met the acceptance criteria for S1.	Envirobond™ exhibits long-term stability, as indicated by the results of this procedure.	
Eh	There was no significant change in Eh at either site, thus this criterion for S1 was not met at either site.	Envirobond™ did not increase long-term stability, as indicated by the results of this procedure.	
pH	pH was significantly increased at one site and significantly decreased at the other site. Results did not meet the acceptance criteria for S1 at either site (see Table 2-4).	Envirobond™ did not increase long-term stability, as indicated by the results of this procedure.	
CEC[1]	All results met the acceptance criteria for S1 (see Table 2-4).	Envirobond™ did not increase long-term stability, as indicated by the results of this procedure.	
Acid neutralization capacity[1]	The criterion for S1 was met for one site, but was not met for the other site.	Envirobond™ did not increase long-term stability, as indicated by the results of this procedure.	Envirobond™ did not increase long-term stability, as indicated by the results of this procedure.
Total lead by nitric acid digestion compared with total lead by hydrofluoric acid digestion	None of the results met the acceptance criteria for S1 (see Table 2-4).	Envirobond™ did not increase long-term stability, as indicated by the results of this procedure.	
SPLP lead	The acceptance criterion for S1 was met at both sites.	Envirobond™ did not increase long-term stability, as indicated by the results of this procedure. However, SPLP lead concentrations appeared to be higher in the treated soils.	
Total phosphate	None of the results met the acceptance criteria for S1 (see Table 2-4).	Envirobond™ did not increase long-term stability, as indicated by the results of this procedure. However, the increase in concentrations of phosphate in treated soils is related only indirectly to long-term stability and therefore is not as meaningful as the findings for most of the other procedures conducted.	
SPLP phosphate	None of the results met the acceptance criteria for Objective S1 (See Table 2-4).	Envirobond™ did not increase long-term stability, as indicated by the results of this procedure.	

[1] Only one sample at each site was tested by this procedure.

Table 2-36. Air Monitoring Results

Area	Date	Time Sampled (minutes)	Flow Rate (L/minute)	Air Volume (L)	Lead Concentration
Area Sample Southwest	9/22/98	5	10	50.0	<4.0 μ g/m³
Area Sample East	9/22/98	5	10	50.0	<4.0μ g/m³
Area Sample Northeast	9/22/98	5	10	50.0	<4.0 μ g/m³
Area Sample North	9/22/98	5	10	50.0	<4.0 μ g/m³
Area Sample Southwest	9/25/98	5	10	50.0	<4.0 μ g/m³
Area Sample East	9/25/98	5	10	50.0	24 μ g/m³
Area Sample Northeast	9/25/98	5	10	50.0	<4.0 μ g/m³
Area Sample North	9/25/98	5	10	50.0	<4.0 μ g/m³

Notes: μ g/m³ = Micrograms per cubic meter of air

cross-contamination as a result of sample collection or shipping procedures. Therefore, this deviation should not impact the overall data quality. All of the soil samples specified in the QAPP for TCLP lead analysis were collected and analyzed. All samples were analyzed within the holding times specified in the QAPP and all of the TCLP lead data were considered usuable. Therefore, the critical parameters of bioavailable and TCLP lead data are considered to be 100 percent complete.

2.5.2 Comparability and Project-required Detection Limits

Based on the consistent implementation of a reference method, pretreatment and post-treatment data for critical parameters (bioavailable lead and TCLP lead) are considered to be comparable. As specified by the QAPP, the University of Colorado used the SBRC In Vitro Method for Determination of Lead and Arsenic Bioaccessibility to analyze soil samples for bioavailable lead and Quanterra used SW-846 Method 1311 (EPA 1996) to analyze soil samples for TCLP lead concentrations. The PRDLs specified in Table 3-1 of the QAPP were achieved for all samples collected during the demonstration.

2.5.3 Accuracy and Precision

Accomplishment of QA objectives for accuracy and precision were evaluated on the basis of MS/MSD percent recoveries and relative percent differences (RPD). Percent recovery and RPD values for LCS/LCSD and blank spike (BS) samples, also supported QA objectives for accuracy and precision.

All of the precision and accuracy assessments for the bioavailable lead data, including the RPD of the duplicates and the percent recoveries of the MS and BS analyses, were within the limits specified in the QAPP. Concentration levels for spiking met the criteria specified in the QAPP for all analyses. The QC data for the critical and noncritical parameters are presented in Appendix B.

One TCLP lead MS/MSD sample had a percent recovery of 124 percent, which is outside the acceptable range of 80 to 120 percent. The batch of samples for which the MS/MSD analysis was performed were all pretreatment samples. Therefore, this deviation should not impact the overall quality of the data for the demonstration. The data on untreated soil are not used to determine whether the technology can meet objective P1, which is to reduce the TCLP lead concentration to a level lower than the alternative UTS lead in soil of 7.5 mg/L. The percent recovery of the LCS/LCSDs were all within the acceptable range of 80 to 120 percent. All of the RPDs for the MS/MSD and LCS/LCSD samples were less than 20 percent and were therefore acceptable.

2.5.4 Representativeness

The University of Colorado analyzed method blank samples for bioavailable lead to confirm the representativeness of the bioavailable lead data by determining if any lead was potentially introduced during sample preparation and analysis. The levels of lead in the method blank samples did not exceed the criteria in the QAPP for method blanks, which is 25 μ g/L. Therefore, the method blank analyses do not indicate that laboratory contamination introduced detectable concentrations of the critical parameter bioavailable lead to any of the samples, and the reported concentrations of the critical parameter bioavailable lead appear to be representative of actual concentrations in the soil samples, based on the available QC data.

Quanterra analyzed method blank samples for TCLP lead to confirm the representativeness of the TCLP lead data by determining if any lead was potentially introduced during sample preparation and analysis. Quanterra did not detect any TCLP lead in any of the method blanks above the PRDL of 0.50 mg/L. Therefore, the method blank analyses do not indicate that laboratory contamination introduced detectable concentrations of the critical parameter TCLP lead to any of the samples, and the reported concentrations of the parameter TCLP lead appear to be representative of actual concentrations in the soil samples, based on the available QC data.

Tetra Tech prepared equipment blank samples and field blank samples to determine if any lead was potentially introduced by sample collection, handling, and packaging procedures. The blank sample preparation techniques are summarized in Section 2.5.1 of the TER. The results of the equipment and field blank analyses are summarized in Tables 4-1 and 4-2 of the TER. No lead was detected in any of these blank samples above the PRDL of 100 μ g/L.

The University of Colorado analyzed the equipment blank and field blank samples for bioavailable lead to confirm the representativeness of the bioavailable lead data by determining if any bioavailable lead was potentially introduced during sample collection, handling and packaging procedures. The University of Colorado did not detect any bioavailable lead in any of the equipment and field blanks above the PRDL of 100 μ g/L. Therefore, the equipment and field blank analyses do not indicate that sample collection, handling and packaging procedures introduced detectable concentrations of the critical parameter bioavailable lead to any of the samples.

Quanterra analyzed the equipment blank and field blank samples for TCLP lead to confirm the representativeness of the TCLP lead data by determining if any lead was potentially introduced during sample collection, handling and packaging procedures. Quanterra did not detect any TCLP lead in any of the equipment and field blanks above the PRDL of 0.50 mg/L. Therefore, the equipment and field blank analyses do not indicate that sample collection, handling and packaging procedures introduced detectable concentrations of critical parameter TCLP lead to any of the samples.

3.0 Technology Applications Analysis

This section describes the Envirobond™ technology. It identifies the waste to which the technology is applicable and discusses the method of application used during the demonstration, materials handling requirements, the limitations of the technology, potential regulatory requirements, key features, the availability and transportability of the technology, and acceptance of the technology by state regulators and communities.

3.1 Description of the Technology

The Envirobond™ process incorporates the application of a mixture of a proprietary powder and liquid that binds with metals in contaminated solid media. The Envirobond™ reagents (liquid and powder) consist of a mixture of additives containing oxygen, sulfur, nitrogen, and phosphorous; each additive has an affinity for a specific class of metals. RMRS claims that the Envirobond™ process converts the metal contaminant from its leachable form to an insoluble, stable, nonhazardous organo-metallic complex. The Envirobond™ reagents are essentially a mixture of ligands that act as chelating agents. In the chelation reaction, coordinate bonds attach the metal ion to at least two ligand nonmetal ions to form a heterocyclic ring. RMRS claims that, by effectively binding the metals, the Envirobond™ process reduces the waste stream's TCLP test results to less than regulated levels, thereby reducing the risks posed to human health and the environment (RMRS, 1999). The Envirobond™ process generates no secondary wastes and requires minimal handling, transportation, and disposal costs.

3.2 Applicable Wastes

RMRS claims that the Envirobond™ process can treat heavy metals in soils, sludges, mine tailings and process residues, and other solid waste. RMRS states the following heavy metals can be stabilized with the Envirobond™ process: arsenic, barium, cadmium, chromium, lead, mercury, nickel, selenium, silver, and zinc (RMRS 1999). According to RMRS, the Envirobond™ process can also stabilize wastes contaminated with various radionuclides, including thorium, uranium, radium, and cesium.

3.3 Method of Application

The Envirobond™ process is applied *in situ* using common farm and construction equipment at large sites, and with simple gardening equipment for smaller treatment areas. For example, the Envirobond™ powder was applied to the surface of the tilled experimental units at the CRPAC demonstration site with a fertilizer drop spreader. The Envirobond™ liquid was applied over the powder using a watering can. The mixture was then tilled into the soil using a garden tiller. If necessary, flyash can be used to adjust the pH of a treatment plot after the application of the Envirobond™ process. The flyash is spread over the surface of the plot and tilled into the soil.

RMRS determines an appropriate, site-specific concentration of the Envirobond™ powder and liquid to be applied by determining the density, volume, weight, and amount of contamination present in the soil through bench-scale studies on soil samples. An evaluation of the soil chemistry at the site must be performed to determine the contaminant concentration throughout the site and the concentration of other metals that may be present at the site. Site conditions such as soil type, depth of contamination, and moisture content must be evaluated to determine the application procedure and equipment requirements.

The site should be accessible to wheeled or tracked vehicles and have sufficient storage space for the equipment required to apply the Envirobond™ process to a specific site. No utilities are required for the application of the Envirobond™ process. Potable water is required for equipment and personnel decontamination.

3.4 Material Handling Requirements

The Envirobond™ powder and liquid are both nonhazardous and require no special handling procedures. To decrease the variability of lead in the soil at the CRPAC, the contaminated soil was tilled to a depth of 6 inches. The soil must be kept moist to prevent airborne transmission of the metals in the soil. Once the soil has been tilled, the Envirobond™ process can be applied. After the application of the Envirobond™ mixture, the soil was tilled again to mix these components into the soil, depending on the soil conditions. Following the soil treatment, all field equipment and personal protection equipment (PPE) must be decontaminated. For the CRPAC demonstration, this was accomplished with soap, water, and Alconox™ detergent, followed by a deionized water rinse. While the Envirobond™ process is expected to generate little residual waste, any soil on the equipment, fluids used in the decontamination process, disposable PPE, and possibly the sod removed from the treatment plot, should be treated as a potentially hazardous waste. This waste should be containerized and characterized for proper disposal.

3.5 Limitations of the Technology

The presence of metals such as aluminum, magnesium, calcium, and manganese at concentrations more than 30 percent by weight can reduce the bonding capability of the Envirobond™ process. RMRS reports that the Envirobond™ process is not effective in treating soil with lead concentrations greater than 30 percent by weight.

3.6 Potential Regulatory Requirements

This section discusses environmental regulations that may pertain to the application of Envirobond™. The applicability of regulations to a particular remediation activity depends on the type of remediation site and the type of waste treated. Remedial managers also must address state and local regulations, which may be more stringent. ARARs for applications of Envirobond™, although site-specific, may include the requirements of following federal regulatory programs: (1) the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); (2) RCRA; (3) OSHA; and (4) the Clean Water Act (CWA).

3.6.1 CERCLA

CERCLA, as amended by the SARA, provides for federal authority and funding to respond to releases or potential releases of any hazardous substance into the environment, as well as to releases of pollutants or contaminants that may present an imminent or significant danger to public health and welfare or to the environment. CERCLA is pertinent to a consideration of Envirobond™ because it governs the selection and application of remedial technologies at Superfund sites.

In general, two types of responses are possible under CERCLA: removal action and remedial action. Remedial actions are governed by the SARA amendments to CERCLA. SARA states a strong regulatory preference for innovative technologies that provide long-term protection and directs EPA to:

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

SARA requires that on-site remedial actions comply with federal and more stringent state and local ARARs. ARARs are determined on a site-by-site basis and may be waived under any of six conditions: (1) the action is an interim measure, and the ARAR will be met at completion; (2) compliance with the ARAR would pose a greater risk to health and the environment than noncompliance; (3) it is technically impracticable to meet the ARAR; (4) the standard of performance of an ARAR can be met by an equivalent method; (5) a state ARAR has not been applied consistently elsewhere; or (6) compliance with the ARAR would not provide a balance between the protection achieved at a particular site and demands on Superfund for addressing other sites. The waiver options apply only to Superfund actions taken on site, and justification for the waiver must be demonstrated clearly (EPA 1988).

3.6.2 RCRA

RCRA, as amended by HSWA, regulates management and disposal of municipal and industrial solid wastes. EPA and the states implement and enforce RCRA and state regulations. Some of the RCRA Subtitle C (hazardous waste) requirements under 40 CFR parts 254 and 265 may apply at CERCLA sites because remedial actions generally involve treatment, storage, or disposal of hazardous waste. However, requirements under RCRA may be waived for CERCLA remediation sites, provided equivalent or more stringent ARARs are met.

RCRA regulations define hazardous wastes and regulate their transportation, treatment, storage, and disposal. The regulations are applicable to uses of Envirobond™ only if hazardous wastes as defined under RCRA are present. If soils are determined to be hazardous under RCRA (either because of a characteristic identified in RCRA or listing of the waste, the remedial manager must address all RCRA requirements governing the management and disposal of hazardous waste. Criteria for identifying characteristic hazardous wastes are set forth in 40 CFR part 261 subpart C. Listed wastes from specific and nonspecific industrial sources, off-specification products, cleanups of spills, and other industrial sources are itemized 40 CFR part 261 subpart D.

Residual wastes generated during the application of Envirobond™ must be stored and disposed of properly. If the treated waste is a listed waste, residues of treatment must be considered listed wastes (unless delisting requirements under RCRA are met). If the residues are not listed wastes, they should be tested to determine whether they are characteristic hazardous wastes as defined under RCRA. If the residues are not hazardous and do not contain free liquids, they can be disposed of in a Subtitle D facility. If the residues are hazardous, the following RCRA standards apply:

- Standards and requirements for generators of hazardous waste, including hazardous treatment residues, are set forth at 40 CFR part 262. The requirements include obtaining an EPA identification number, meeting waste accumulation standards, labeling wastes, and keeping appropriate records. Part 262 allows generators to store wastes for as much as 90 days without a permit. If residues of treatment are stored on site for 90 days or more, requirements set forth at 40 CFR part 265 are applicable.
- Any on- or off-site facility designated for permanent disposal of residues of hazardous treatment must be in compliance with RCRA. Disposal facilities must fulfill the permitting, storage, maintenance, and closure requirements at 40 CFR parts 264 through 270.

In addition, any authorized state RCRA requirements must be fulfilled. If treatment residues are disposed of off site, transportation standards set forth at 40 CFR part 263 are applicable.

3.6.3 OSHA

OSHA regulations at 29 CFR parts 1900 through 1926 are designed to protect the health and safety of workers. Corrective actions undertaken under both Superfund and RCRA must meet OSHA requirements, particularly those set forth at Section 1910.120, Hazardous Waste Operations and Emergency Response. Any more stringent state or local requirements must also be met. In addition, health and safety plans for site remediation projects should address chemicals of concern and include monitoring practices to ensure that the health and safety of workers are protected.

PPE must be worn to protect field personnel from known or suspected physical hazards, as well as air-, soil-, and water-borne contamination. The levels of PPE to be used for work tasks must be selected on a site-specific basis. The level of PPE should be based on known or anticipated physical hazards and concentrations of contaminants that may be encountered at a particular site and their chemical properties, toxicity, exposure routes, and contaminant matrices. Personnel must wear PPE when site activities involve known or suspected atmospheric contamination; when site activities might generate vapors, gases, or particulates; or when direct contact with substances that affect the skin may occur. Full-face respirators may be necessary to protect lungs, the gastrointestinal tract, and eyes against airborne contaminants. Chemical-resistant clothing may be needed at certain sites to protect the skin from contact with chemicals that are absorbed through or destructive to the skin.

The information provided by RMRS and the results of observations made during the demonstration project indicate that the contaminants being treated usually are the determinating factor in the selection of PPE for applications of Envirobond™. In general, latex or nitrile gloves, Tyvek coveralls, boot covers, and goggles are recommended for applying Envirobond™ to contaminated soils.

3.6.4 CWA

The CWA is designed to restore and maintain the chemical, physical, and biological quality of navigable surface waters by establishing federal, state, and local discharge standards. The CWA may affect application of the technology because it governs the appropriate manner of managing water used for decontamination activities. Depending on the concentrations of the contaminants in the wastewater and any permit requirements, contaminated water from the decontamination procedures could be discharged to a publicly owned treatment works (POTW). Each POTW has a different limit for lead that is specified in the POTW's National Pollutant Discharge Elimination System (NPDES) permit. The POTW will require disclosure of the contents of the wastewater and will determine whether contaminants will interfere with the treatment of the wastewater.

3.7 Availability and Transportability of the Technology

The Envirobond™ process is available from Rocky Mountain Remediation Services of Golden, Colorado, (see Section 1.4 for address and telephone number). The proprietary powder and liquid are completely nonhazardous and were transported to the CRPAC demonstration site by a medium-duty truck, which did not require any special permits or licensing to transport the material. According to RMRS, there are no restrictions on other methods of transporting the materials. All typical equipment required for the application of the Envirobond™ process are generally readily available from local rental companies and do not need to be obtained from RMRS.

3.8 Community Acceptance by the State and the Community

State and community acceptance of Envirobond™ on the part of state regulatory agencies and affected communities likely will be site-specific. Because no community outreach program has been established for the CRPAC, it is difficult to predict how communities in the vicinity of the CRPAC will accept Envirobond™.

4.0 Economic Analysis

This economic analysis presents two cost estimates for the application of Envirobond™ (not including profit) to commercially remediate soil contaminated with lead. The estimates are based on assumptions and costs provided by RMRS; data compiled during the SITE demonstration; and additional information obtained from current construction cost estimating guidance, as well as experience under the SITE Program. Costs for the technology can vary, depending on soil conditions, regulatory requirements, and other site- and waste-specific factors.

Two estimates are presented in this analysis to determine the costs of applying Envirobond™. The first estimate (Case 1) is based on costs incurred during the SITE demonstration. The total volume of soil treated at the CRPAC demonstration site was approximately 5 cubic yards. That volume was spread over ten 5-foot-by-5-foot-by-0.5 foot plots and one 6-foot-by-3-foot-by-0.5 foot plot. The second estimate (Case 2) is for a hypothetical one-acre site at the CRPAC that would be treated to depth of 0.5-foot. Case 2 represents a typical application of Envirobond™. The cost estimate for Case 2 is based on extrapolation of data from the costs of the SITE demonstration. For Case 2, the total volume of soil to be treated is 807 cubic yards. Two scenarios are presented because of certain “fixed” costs related to the use of the technology, the unit cost per volume drops significantly when it is applied to larger volumes of material.

This section summarizes factors that influence costs, presents assumptions used in the analysis, discusses estimated costs, and presents the conclusions of the economic analysis. Table 4-1 presents the estimated costs generated by the analysis. Costs have been distributed among 12 categories that are applicable to typical cleanup activities at Superfund and RCRA sites (Evans 1990). Costs are presented in 1998 dollars, are rounded to the nearest 100 dollars, and are considered to be minus 30 percent to plus 50 percent order-of-magnitude estimates.

4.1 Factors that Affect Costs

Costs for implementing Envirobond™ can be affected by site-specific factors, including the regulatory status of the site, waste-related factors, total volume of soil to be treated, site features, and soil conditions. The regulatory status of the site typically depends on the type of waste management activities that occurred at the site, the relative risk to nearby populations and ecological receptors, the state in which the site is located, and other factors. The site’s regulatory status affects costs because it makes the site subject to mandates related to ARARs and remediation goals that may affect the system design parameters and the duration of the remediation project. Certain types of sites may be subject to more stringent monitoring requirements than others, depending on the regulatory status of the individual site. Soil conditions at the site determine the possible treatment depth, which can affect costs.

Factors related to the waste that affect costs include the volume, distribution, and type of contamination at the site, which have a direct effect on site preparation costs; the amount of Envirobond™ needed; and the amount of time necessary to treat the soil. The type and concentration of the contaminant also will affect disposal costs for wastes generated by the remediation effort.

The location and physical features of the site will affect the cost of mobilization, demobilization, and site preparation. Mobilization and demobilization costs are affected by the distances that system materials must be transported to the site. For high-visibility sites in densely populated areas, stringent security measures and minimization of obtrusive construction activities, noise, dust, and air emissions may be necessary. Sites requiring extensive surficial preparation (such as constructing access roads, clearing large trees, or working around or demolishing structures) or restoration activities also will incur higher costs than sites that do not require such preparation. The availability of existing electrical power and water supplies may facilitate construction activities and lower costs. In the United States significant regional variations may occur in the costs of materials, equipment, and utilities.

4.2 Assumptions of the Economic Analysis

For Case 1, existing technology and site-specific data from the demonstration were used to present the costs of applying Envirobond™ at the CRPAC demonstration site. Certain assumptions were made to account for variable site and waste parameters for Case 2. In general, most system operating issues and assumptions are based on information provided by RMRS and observations made during the SITE demonstration. For both cases, costs were based on information provided by RMRS, observations made and data collected during the SITE demonstration, current environmental restoration cost guidance (R.S. Means [Means] 1998), and experience under the SITE program.

Table 4-1. Cost Distribution for Envirobond™

Cost Categories	Case 1 (5 yd^3)			Case 2 (807 yd^3)		
	Costs	Cost/yd^3	% Costs	Costs	Cost/yd^3	% Costs
(1) Site Preparation						
Rental Equipment	$30			$115		
Labor and Per Diem	$1,350			$1,350		
Total Site Preparation Costs	$1,400	$280	$5.41	$1,500	$1.86	$4.52
(2) Permitting and Regulatory	—-	—-	—-	—-	—-	—
(3) Mobilization						
Mileage	$400			$400		
Labor and Per Diem	$3,100			$3,100		
Total Mobilization Costs	$3,500	$700	$13.52	$3,500	$4.34	$10.54
(4) Equipment						
Rental Equipment	$50			$700		
Purchased Equipment	$250			—-		
Total Equipment Costs	$300	$60	$1.16	$700	$0.87	$2.11
(5) Labor						
Labor	$12,100			$7,320		
Per Diem	$2,480			$800		
Total Labor Costs	$14,580	$2,916	$56.34	$8,120	$10.06	$24.44
(6) Supplies and Materials						
Envirobond™	$100			$8,900		
Sampling Supplies	$200			$400		

Note: 1998 dollars.

(continued)

Table 4-1. Cost Distribution for Envirobond™ (continued)

Cost Categories	Case 1 (5 yd^3)			Case 2 (807 yd^3)		
	Costs	Cost/yd^3	% Costs	Costs	Cost/yd^3	% Costs
PPE and Decontamination Supplies	$500			$800		
Misc. Field Supplies	$200			$900		
Total Supplies and Materials Costs	$1,000	$200	$3.86	$11,000	$13.63	$33.11
(7) Utilities	—-	—-	—-	—-	—-	—
(8) Effluent Treatment & Disposal	—-	—-	—-	—-	—-	—
(9) Residual Waste Shipping	—-	—-	—-	$700	$0.87	$2.11
(10) Analytical Services	$1,600	$320	$6.18	$4,200	$5.20	$12.64
(11) Equipment Maintenance	—-	—-	—-	—-	—-	—
(12) Site Demobilization						
Mileage	$400			$400		
Labor and Per Diem	$3,100			$3,100		
Total Site Demobilization Costs	$3,500	$700	$13.52	$1,500	$4.34	$10.54
Total Costs	$25,880	$5,176	$100.00	$33,220	$41.16	$100.00

Note: 1998 dollars.

For both cases, assumptions made about site- and waste-related factors for both cases include:

- The two sites are located in the CRPAC, where disposal of broken and "off-spec" pottery having lead-based glazes has contaminated the soil with lead.
- The total volume of material treated for Case 1 is approximately 5 cubic yards. The total volume of soil to be treated for Case 2 is 807 cubic yards.
- There is an existing access road, and there are no accessibility problems associated with the two sites.
- There are no structures on either site that require demolition. No utilities are present that require relocation or that restrict operation of heavy equipment.
- For Case 1, it is assumed that the sod covering the site can be removed with sod cutters and can be replaced after the soil has been treated. For Case 2, it is assumed that some clearing and grubbing will be necessary to prepare the site for the application of Envirobond™.
- Electricity for both sites can be provided by a portable generator.
- For both cases, the highest levels of contaminated soil extend from the ground surface to a depth of approximately 6 inches below ground surface.
- This estimate assumes that the wastes generated during the application of Envirobond™ are limited to those produced during decontamination of equipment used during the application. For Case 1, residual waste will be disposed of on site. For Case 2, waste generated during the decontamination activities can be treated and disposed of at easily accessible facilities. Wastewater can be discharged to a POTW for $1 per gallon. Nonhazardous solid waste can be transported and disposed of for $60 per ton.

For both cases, the assumptions about system design and operating parameters for both cases include:

- RMRS provides on-site personnel during all phases of the treatment.

- An hourly labor rate of $47.40 is used for site preparation and sampling activities. The rate represents the average labor rate, based on the demonstration. A labor rate of $54 per hour is used for all other activities. That is the rate used by RMRS for a field chemist.

- A per diem of $80 per worker per day is assumed.

- Routine labor requirements consist of soil preparation, sampling of untreated and treated soil, and application of Envirobond™.

- Maintenance costs are included in the equipment rental cost.

- Envirobond™ liquid and powder are transported from the office of RMRS in Golden, Colorado, to the CRPAC.

- It is assumed that 22 samples are collected for Case 1, and 58 samples are needed for Case 2.

- Costs are presented as 1998 dollars.

- There are no utility costs for either case.

4.3 Cost Categories

Table 4-1 presents cost breakdowns for each of the 12 cost categories for Envirobond™: (1) site preparation, (2) permitting and regulatory, (3) mobilization, (4) capital equipment, (5) labor, (6) supplies and materials, (7) utilities, (8) effluent treatment and disposal, (9) residual waste shipping and handling, (10) analytical services, (11) equipment maintenance, and (12) site demobilization. Each of the 12 cost categories is discussed below. The costs for each category have been rounded up to the nearest $50 or $100.

4.3.1 Site Preparation Costs

For the purposes of this economic analysis, it is assumed that preliminary site preparation will be performed by the responsible party (or site owner). The amount of preliminary site preparation required will depend on the site. Site preparation responsibilities include site design and layout, surveys and site logistics, legal searches, access rights and roads, preparation for support and decontamination facilities, utility connections (if needed), and potentially, fixed auxiliary buildings. Since these costs are site-specific, they are not included as part of the site preparation costs in the estimates.

For this cost analysis, only technology-specific site preparation costs are included. These costs are limited to preparing the site for the application of the Envirobond™ process by tilling the soil to the appropriate treatment depth, and removing the grass covering the site with a sod cutter or by tilling it into the soil. The treatment depth for both cases is 6 inches. Site preparation costs for both cases are presented in Table 4-2.

For Case 1, sod covering the site is assumed to be removed with sod cutters and stored until it can be replaced after the treatment. Site preparation costs for Case 1 include rental costs for sod removal and tilling equipment, labor, and per diem. Assuming three workers, earning an estimated labor rate of $47.40 per hour, can prepare the site in 8 hours (one business day), the total labor cost associated with site preparation activities for Case 1 is approximately $1,100. A per diem of $80 per worker per day is assumed, adding an additional $240 to the total site preparation cost. Weekly rental costs for the tiller and sod cutters, determined from actual demonstration costs, are approximately $200, bringing the daily rental cost to approximately $30. Therefore, the total cost for site preparation for Case 1 is estimated to be approximately $1,400.

For Case 2, site preparation costs include costs associated with tilling equipment, labor, and per diem. Since the site will have to be tilled with larger, production-sized equipment, it is assumed that the 1-acre site can be prepared in 8 hours and that all grass covering the site will be tilled into the soil. Tilling equipment for the 1-acre site would include a medium-duty tractor with a plow. Based on several vendor quotes, the weekly rental rate for this equipment is estimated to be $800, bringing the daily cost for this equipment to approximately $115. Assuming three workers, earning an estimated labor rate of $47.40 per hour, labor costs associated with Case 2 will be $1,100. The total per diem for the 3 workers is $240. This brings the total site preparation costs for Case 2 to an estimated $1,500.

4.3.2 Permitting and Regulatory Costs

Permitting and regulatory costs are generally the obligation of the responsible party (or site owner), and not that of the vendor. These costs may include actual permit costs, system monitoring requirements, the development of monitoring and analytical procedures, and health and safety monitoring. Permitting and regulatory costs can vary greatly because they are site-and waste-specific. In applications of the Envirobond™ process as part of a soil remediation program, permitting and regulatory costs will vary depending on whether remediation is performed at a Superfund or RCRA corrective action site. Superfund site remedial actions must be consistent with ARARs of environmental laws, ordinances, regulations, and statutes, including federal, state, and local standards and criteria.

Table 4-2. Site Preparation Costs

Cost Category	Case 1	Case 2
Rental equipment	$ 30	$ 115
Labor (24 hours total) ($47.40/hour x 8 hrs x 3 workers)	$ 1,100	$ 1,100
Per diem ($80/worker/day x 1 day x 3 workers)	$ 240	$ 240
Total Site Preparation Costs	$ 1,400	$ 1,500

Note: 1998 dollars.

Remediation at RCRA corrective action sites requires additional monitoring and recordkeeping, which can increase the base regulatory costs.

No permitting costs are included in this analysis; however, depending on the treatment site, they may be a significant factor since permitting can be expensive and time consuming. These costs are not included in this analysis because no regulatory permits were required for Case 1. This was due to the fact that the demonstration sites were neither Superfund nor RCRA sites. Permits may be needed for air emissions if the site preparation activities produce significant quantities of dust. However, air emissions can be controlled by wetting the soil to be treated during the tilling activities. These costs are expected to be negligible and are not included in this estimate. For Case 2, it is assumed that no permitting and regulatory costs will be incurred for air emissions or for the transportation and disposal of residual wastes generated during the treatment activities. This is based on the assumption that wastes generated for Case 2 will be nonhazardous and can be transported and disposed of at a Subtitle D landfill for $60 per ton. Residual wastes generated at other sites may be classified as hazardous waste, and would require the transport and disposal facility to have appropriate RCRA permits.

4.3.3 Mobilization Costs

Table 4-3 presents the mobilization costs for both cases. Mobilization costs consist of mobilizing personnel and transporting materials to the site. For both cases, it is assumed that some equipment and materials are transported by a medium-duty truck from the office of RMRS in Golden, Colorado, to the CRPAC. The distance between Golden, Colorado, and the CRPAC site in Crooksville/Roseville, Ohio, is approximately 1,350 miles. RMRS mobilized two field personnel and one truck for the SITE demonstration. It is assumed that for Case 2, two personnel and one truck will also be mobilized. Assuming the standard government mileage reimbursement rate of 31 cents per mile, mileage costs from Golden, Colorado, to the CRPAC were approximately $400. The drive from Golden, Colorado, to the CRPAC site requires approximately 24 hours of driving time. Labor costs for mobilizing two personnel (for a total of 48 hours of labor) earning an estimated labor rate of $54 per hour are approximately $2,600. Assuming the trip is completed in 3 days, and a per diem of $80 per worker per day, the total per diem charges for two people is $480. The total mobilization cost for both cases is approximately $3,500. Mobilization of personnel and materials to other sites could be accomplished in a number of ways. For example, materials could be shipped by a carrier service and personnel flown to the site. These options should be explored to minimize the cost of mobilization.

4.3.4 Equipment Costs

Equipment costs for both cases are presented in Table 4-4. Rental equipment used for Case 1 consisted of a tiller to loosen and mix the soil at the site. This equipment was used over a 2-day period. The daily rental cost for the tiller is approximately $23 (when rented for 1 week). Therefore, the total cost of rental equipment for Case 1 was approximately $46. Purchased equipment used for Case 1 consisted of a watering can, fertilizer spreader, a graduated cylinder for mixing the Envirobond™ process, and a pressure sprayer for decontamination. The total cost for purchased equipment for Case 1 was approximately $250. Therefore, the total cost of equipment for Case 1 is approximately $300.

It is assumed that for Case 2 the application of the Envirobond™ process will require larger, production-sized equipment. The equipment necessary for Case 2 should be rented in order to minimize costs. Equipment for Case 2 is assumed to be a tractor with both a plow and a fertilizer spreader, and a 2500-pounds per square inch (psi) pressure washer for decontamination. For Case 2, it is assumed that the treatment will require 3 days. The daily rental cost for the tractor and plow is approximately $115, bringing the cost for this equipment to $345 for the 3-day period. The combined 1-week rental rates for the pressure washer and the fertilizer sprayer are estimated to be $800, bringing the daily rental cost for this equipment to $115. For the 3-day time period assumed for Case 2, the cost for the pressure sprayer and the fertilizer sprayer is $345. Therefore, the total equipment cost for Case 2 is estimated at approximately $700.

4.3.5 Labor Costs

Once the site has been prepared and the technology has been mobilized, labor requirements for applying the Envirobond™ process are minimal. Labor costs are summarized in Table 4-5. Sampling labor costs for Case 1 con-

Table 4-3. Mobilization Costs

Cost Category	Case 1	Case 2
Mileage	$ 400	$ 400
Labor (40 hours total) ($54/hr x 20 hrs x 2 workers)	$ 2,600	$ 2,600
Per diem ($80/worker/day x 3 days x 2 workers)	$ 480	$ 480
Total Mobilization Costs	$ 3,500	$ 3,500

Note: 1998 dollars.

Table 4-4. Equipment Costs

Cost Category	Case 1	Case 2
Rental equipment	$ 50	$ 700
Purchased equipment	$ 250	—
Total Capital Equipment Cost	$ 300	$ 700

Note: 1998 dollars.

sisted of five field personnel for 5 days, at an estimated labor rate of $47.40 per hour. During the demonstration project, sample collection efforts included collecting significantly more samples than would be expected for Case 2. Therefore, it is assumed that two field personnel will be required for Case 2 sampling activities, at an estimated labor rate of $47.40 per hour. It is also assumed that two workers will be required for the treatment activities, at a rate of $54 per hour. All workers are assumed to receive a per diem of $80 per day to cover lodging, food, and expenses. For Case 1, it is assumed that the amount of time required to sample and treat the site will be the same as that required for the SITE demonstration. Pretreatment and post-treatment sampling activities lasted 5 days, and required a total of 200 hours of labor. Labor costs associated with the sampling activities for Case 1 were approximately $9,500. The treatment performed by RMRS required 24 hours and lasted 3 days, for a total of 48 hours of labor. The total labor cost for the treatment activities associated with Case 1 was approximately $2,600. The total per diem for two workers over the 5-day period was $800. Therefore, the total labor costs associated with Case 1, including per diem, was $5,500.

For Case 2, sampling activities will require a total of 64 hours of labor, bringing the total labor costs for the sampling activities for Case 2 to $3,000. It is assumed that treatment activities for Case 2 will require approximately 80 hours of labor over a 5-day period, bringing labor costs associated with treatment activities for Case 2 to an estimated $4,320. The total labor cost for Case 2 is estimated to be approximately $7,320. The total per diem for two workers over the 5-day period is $800. Therefore, the total labor costs associated with Case 2, including per diem, is estimated to be $8,120. Labor costs associated with laboratory analytical costs are included in Section 4.3.10, Analytical Services.

4.3.6 Supplies and Materials Costs

The necessary supplies for the soil sampling activities and the application of the Envirobond™ process include the Envirobond™ mixture, sampling supplies, Level D disposable PPE (latex rubber gloves), decontamination supplies, and miscellaneous field supplies. The costs for supplies and materials are presented in Table 4-6. The total cost of the Envirobond™ mixture reported by RMRS for Case 1 was $55 (RMRS 1999). Disposable PPE typically consists of latex inner gloves and nitrile outer gloves. Decontamination supplies consist of soap, deionized water, and Alconox. PPE and decontamination supplies cost approximately $500 for Case 1. Sampling supplies include sample bottles, labels, a 5-gallon bucket with lid, sieves, and shipping containers. Sampling supplies cost approximately $200 for Case 1. Field supplies include water for personnel, coolers, field notebooks, an outdoor canopy, and other miscellaneous supplies. Field supplies cost an estimated $200. Total supply and materials costs for Case 1 were approximately $1,000.

For Case 2, it is assumed that approximately 161 times as much soil (by volume) will be treated with the Envirobond™ mixture. Assuming a linear cost to volume ratio, the total cost of the Envirobond™ mixture for Case 2 is estimated to be approximately $8,900. Because Case 2 represents a larger application of the technology, expenses for PPE, decontamination supplies, sampling supplies, and field supplies are expected to be higher than the costs associated with Case 1. PPE and decontamination supplies are estimated to cost approximately $800 for Case 2. Sampling supplies are expected to cost approximately $400 for Case 2. The cost of field supplies for Case 2 is estimated to be $900. This brings the total supply cost for Case 2 to approximately $11,000.

4.3.7 Utilities Costs

Electricity is not required for the application of the Envirobond™ process. For this reason, no electrical utility connection costs are associated with either case. Water is required to mix the Envirobond™ solution on site, for personnel, equipment decontamination, and possibly ground wetting to control dust. Water costs are insignificant and are therefore not included in the estimate.

4.3.8 Effluent Treatment and Disposal Costs

No effluent is produced during the application of Envirobond™.

4.3.9 Residual Waste Shipping and Handling Costs

One of the key features of the Envirobond™ process is that it does not produce significant amounts of residual waste. Residual wastewater is generated during decontamination

Table 4-5. Labor Costs

Cost Category	Case 1	Case 2
Sampling Labor ($47.40/hr x hours)	9,500 (200 hours total)	3,000 (64 hours total)
Treatment Labor ($54/hr x hours)	2,600 (48 hours total)	4,320 (80 hours total)
Per Diem ($80/worker/day x 5 days x 2 workers)	2,480	800
Total Labor Costs	14,580	8,120

Note: 1998 dollars.

Table 4-6. Supplies and Materials Costs

Cost Category	Case 1	Case 2
Envirobond™ Mixture	$100	$8,900
Sampling Supplies	$200	$400
PPE + Decontamination Supplies	$500	$800
Miscellaneous Field Supplies	$200	$300
Total Supplies and Materials Costs	$1,000	$11,000

Note: 1998 dollars.

of equipment and personnel. For Case 1, the amount of residual wastewater was negligible. OEPA determined the residual wastewater would not further impact the soil or groundwater on the site, and allowed the disposal of the wastewater on site by pouring the wastewater onto the soil in the demonstration area. Therefore, no costs for disposal of wastewater are included in the analysis for Case 1. It is assumed that the only solid wastes generated from the application of the Envirobond™ process are used disposable PPE and soil derived during the decontamination of field equipment. For Case 1, the amount of residual solid waste was negligible. The small amount of residual waste produced during the demonstration was classified as nonhazardous. The waste was disposed as solid waste. The owner of the property provided a dumpster for the disposal of the waste. Therefore, no costs for residual waste disposal are included in this estimate for Case 1.

For Case 2, it is assumed that one 55-gallon drum of residual wastewater will be generated during the decontamination activities. For this cost estimate, it is assumed that the disposal cost is $500 per 55-gallon drum. It is also assumed that one 55-gallon drum of nonhazardous solid waste will be generated. The disposal cost for non-hazardous solid waste is estimated at $200 per 55-gallon drum. Therefore, the total estimated cost for residual waste disposal for Case 2 is $700. If the residual solid waste was hazardous, disposal costs would likely be more expensive.

4.3.10 Analytical Services Costs

Analytical services include costs for laboratory analyses, data reduction, and QA/QC. Sampling frequencies and number of samples are highly site-specific. Therefore, the costs reflected in this analysis may not be applicable to other sites. A total of 292 samples were collected at the CRPAC demonstration site, which included 145 samples collected during the pretreatment stage and 147 samples collected during the post-treatment stage of the demonstration. The large number of samples were taken to make certain that the stringent demonstration objectives could be thoroughly evaluated.

For Case 1, which represents a demonstration-sized or pilot-scale application of the technology, fewer samples will be needed. It is assumed that one composite sample will be taken from each of the 11 plots during the pretreatment and post-treatment sampling events, for a total of 22 samples for Case 1. It is also assumed that for both cases the TCLP will be the only parameter analyzed, since this will determine whether the treatment has reduced metal concentrations to below the regulated levels. The average unit cost per sample for the TCLP analyses performed for the SITE demonstration was $73. This figure includes analytical services costs for standard QA/QC samples. Since the site characteristics for both cases are assumed to be identical to the CRPAC demonstration site, it is assumed that the average cost per sample will remain the same. For Case 1, the total analytical costs for the TCLP analysis of 22 samples is approximately $1,600.

For Case 2, it is estimated that 58 composite samples must be taken to obtain a statistically valid population. In order to estimate the number of samples, treated TCLP data from the SITE demonstration was used and assumed to be representative of the variance (0.35 $[\mathrm{mg/L}]^2$) of treated lead concentrations at the Case 2 site. It was assumed that this data set could be adequately described by a normal distribution. A hypothesis test was set up to compare the treated concentration to 7.5 mg/L (10 times the UTS, and the regulatory action level), with the null hypothesis stating that the average treated concentration is greater than 7.5 mg/L.

Sample size calculations are based on using the one sample t-test statistic. Equation 4-1 was used to determine the appropriate number of samples.

$$n = Var\,(\Delta)\,[(Z_\alpha + Z_\beta) / \delta^2] \tag{4-1}$$

where

$Var\,(\Delta)$ = Variance of the treated data from the SITE demonstration

δ = Minimum detectable difference from 10 times the UTS

Z_α = Value from standard normal such that α is the area under the curve to the right of this value

Z_β = Value from standard normal such that β is the area under the curve to the left of this value

The variables α and β are probabilities associated with Type I and Type II errors, respectively. For this analysis, an α level of 0.1 was defined as acceptable to meet the goals of the study. A β level of 0.1 was used with a minimum detectable difference (δ), of 0.2 mg/L. Values for Z_α and Z_β were obtained from a table of standard normal values.

In order to obtain the desired confidence levels (90 percent) and minimum detection level (0.2 mg/L), at least 58 composite samples must be analyzed at the site. Therefore, the 58 samples to be analyzed by the TCLP bring the total analytical costs for Case 2 to an estimated $4,200.

4.3.11 Equipment Maintenance Costs

All equipment used in the application of the Envirobond™ process can be rented. This option, coupled with the fact that the Envirobond™ process can be applied in a short period of time, eliminates the need for on-site equipment maintenance. For these reasons, no maintenance costs are included in this analysis. Equipment maintenance costs, for projects other than the two cases considered in this analysis, may need to be considered depending on the volume of soil to be treated, soil conditions, and the length of time required to treat the contaminated soil.

4.3.12 Site Demobilization Costs

Site demobilization costs consist of demobilizing personnel and transporting materials from the site. For both cases, it is assumed that some equipment and materials are transported by a medium-duty truck from the demonstration site to the office of RMRS in Golden, Colorado. The distance between the CRPAC site in Roseville, Ohio, to Golden, Colorado, is approximately 1,350 miles. RMRS demobilized two field personnel and one truck. It is assumed that for Case 2, two personnel and one truck will also be demobilized. Assuming the standard government mileage reimbursement rate of 31 cents per mile, mileage costs from the demonstration site to Golden, Colorado, were approximately $400. The drive from the demonstration site to Golden, Colorado, requires approximately 24 hours of driving time. Labor costs for demobilizing two personnel (for a total of 48 hours of labor) earning an estimated labor rate of $54 per hour are approximately $2,600. Assuming the trip is completed in three days, and a per diem of $80 per worker per day, the total per diem charges for two personnel is $480. The total site demobilization cost for both cases is approximately $3,500. Demobilization of personnel and materials to other sites could be accomplished in a number of ways. For example, materials could be shipped via a carrier service and personnel flown from the site. These options should be explored to minimize the cost of demobilization. Table 4-7 presents a summary of site demobilization costs for Case 1 and Case 2.

4.4 Summary of the Economic Analysis

Two cost estimates are presented for applying the Envirobond™ process to remediate lead-contaminated soil in the CRPAC. Both cases are based directly on costs from the demonstration. The first case (Case 1) involves a cost estimate for a demonstration-scale application, and the second case (Case 2) involves a larger 1-acre site having conditions identical to those encountered at the Case 1 site. Table 4-1 shows the estimated costs and the percent distributions associated with the 12 cost categories presented in this analysis for both cases.

For Case 1, important cost categories included site preparation (5.41 percent), mobilization (13.52 percent), labor (56.34 percent), supplies and materials (3.86 percent), analytical services (6.18 percent) and site demobilization (13.52 percent). No costs were incurred in the other cost categories (permitting and regulatory, utilities, effluent treatment and disposal, residual waste shipping and handling, and equipment maintenance) for Case 1. For Case 2, important cost categories included mobilization (10.54 percent), labor (24.44 percent), supplies and materials (33.11 percent), analytical services (12.64 percent), and site demobilization (10.54 percent). The costs for site preparation (4.52 percent), equipment (2.11 percent), and residual waste shipping and handling (2.11 percent), were also significant for Case 2. No costs were incurred in the other cost categories (permitting regulatory, utilities, and equipment maintenance) for Case 2.

Table 4-7. Site Demobilization Costs

Cost Category	Case 1	Case 2
Mileage	$400	$400
Labor (40 hours total) ($54/hr x 20 hrs x 2 workers)	$2,600	$2,600
Per diem ($80/worker/day x 3 days x 2 workers)	$480	$480
Total Demobilization Costs	$3,500	$3,500

Note: 1998 dollars.

5.0 Technology Status

RMRS has completed several bench-scale studies and pilot-scale tests on soil and debris contaminated with heavy metals and radionuclides. Appendix B provides details on some of the projects where the Envirobond™ process has been tested or applied on a full-scale basis.

The Envirobond™ process is currently being used to stabilize waste and debris contaminated with radionuclides at several full-scale sites. The SITE demonstration in Roseville, Ohio, was the second pilot-scale demonstration that RMRS has completed (Tetra Tech 1999d).

References

Canadian Society of Soil Science. 1993. "Soil Sampling and Methods of Analysis." Chapters 19 and 38. Lewis Publishers. 1993.

Evans, G. 1990. "Estimating Innovative Treatment Technology Costs for the SITE Program." *Journal of Air and Waste Management Association.* Volume 40, Number 7. July.

Environment Canada Method Number 7.

Interstate Technology and Regulatory Cooperation (ITRC) Work Group. 1997. "Emerging Technologies for the Remediation of Metals in Soils: *In situ* Stabilization/Inplace Inactivation." December.

R.S. Means, Company, Inc. 1998. *Environmental Restoration Assemblies Cost Book*. R.S. Means Company, Inc., Kingston, Massachusetts.

Northern Kentucky University (NKU). 1999. Letter Regarding Technical Review of Soil Amendment Technologies, Cation Exchange Capacity Assessment. From Lee Otte, Senior Consultant. To David Gilligan, Project Manger, Tetra Tech EM Inc. (Tetra Tech) October 7.

Ohio Environmental Protection Agency. 1998. "Interim Report and Proposal for Additional Work, Crooksville/Roseville Pottery Area of Concern Geographic Initiative." March. Prepared for Environmental Protection Agency.

Rocky Mountain Remediation Services, L.L.C. (RMRS) 1999. Facsimile Regarding Costs Associated with the Envirobond™ Process. From Mike Harper, RMRS, to David Remley, Tetra Tech. July.

Solubility/Bioavailability Research Consortium (SBRC). 1998. "Simplified In Vitro Method for Determination of Lead and Arsenic Bioaccessibility" Unpublished.

Tessier, A. 1979. "Sequential Extraction Procedure for the Speciation of Particulate Trace Metals." *Analytical Chemistry.* Volume 51, Number 7. Pages 844-850.

Tetra Tech EM Inc. (Tetra Tech) 1998. "Evaluation of Soil Amendment Technologies at the Crooksville/Roseville Pottery Area of Concern: SITE Program Final Quality Assurance Project Plan." Prepared for EPA under Contract No. 68-35-0037. November.

Tetra Tech 1999a. "Technology Capsule for Rocky Mountain Remediation Services Envirobond™ Process." July.

Tetra Tech 1999b. Rocky Mountain Remediation Services, L.L.C. "Evaluation of Soil Amendment Technologies at the Crooksville/Roseville Pottery Area of Concern: SITE Program Demonstration Technology Evaluation Report." Prepared for EPA under Contract No. 68-35-0037. December.

Tetra Tech 1999c. "Evaluation Bulletin for Rocky Mountain Remediation Services Envirobond™ Process." June.

Tetra Tech 1999d. Telephone communication between Chris Preston, Tetra Tech, and Rich Jensen, RMRS. August 6.

U.S. Environmental Protection Agency (EPA). 2000. EPA Region 9 Preliminary Remediation Goals (PRG 2000) November http://www.epa.gov/region09/waste/sfund/prg/index.htm

EPA. 1988. Protocol for a Chemical Treatment Demonstration Plan. Hazardous Waste Engineering Research Laboratory. Cincinnati, Ohio. April.

EPA. 1996. Test Methods for Evaluating Solid Waste, Volumes IA-IC: Laboratory Manual, Physical/Chemical Methods; and Volume II: Field Manual, Physical/Chemical Methods, SW-846, Third Edition, Update III, Office of Solid Waste and Emergency Response, Washington D.C. December.

EPA. 1983. Methods for Chemical Analysis of Water and Wastes EPA –600/4-79-020, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio, and subsequent EPA-600/4 technical additions.

Appendix A Vendor Claims

(Note: All information in this appendix was provided by the vendor, Rocky Mountain Remediation Services (RMRS). Inclusion of any information is at the discretion of RMRS, and does not necessarily constitute U.S. Environmental Protection Agency concurrence or endorsement.)

A1. Introduction

In the past five years, Rocky Mountain Remediation Services, L.L.C. (RMRS) has developed and field deployed an innovative, easy to use process for immobilizing heavy metals in soils and soil-like waste. This process uses a non-hazardous chemical binder called Envirobond™ that chemically binds metal contaminants, preventing leaching under the most stringent conditions. RMRS has successfully deployed the technology at locations throughout the United States. Envirobond™ can be adapted in a variety of ways at mining sites, soil washing projects, sediment removal sites, and others to produce a treated product that meets criteria for on-site containment, storage, or off-site disposal. The technology can be adapted for a variety of waste streams and soil conditions, and binds many types of heavy metals at high levels of contamination, including arsenic, barium, chromium, lead, silver, cadmium, selenium, and zinc below the Resource Conservation and Recovery Act (RCRA) treatment standards. Laboratory data indicate that the binder is also effective in treating radionuclides such as uranium, thorium, radium, and strontium.

When desired, the Envirobond™ process can be taken a step further to produce a solidified monolith, called Envirobrics™. Envirobric™ has also been developed and tested for chemical and physical stability, including laboratory, pilot and full scale testing. It resists water, and has passed a 24-hour immersion test. The Envirobric™ process uses off-the-shelf, high throughput equipment, and is therefore highly cost-effective. It also reduces the bulking factor and volume of the final waste form to 30%-40%, which makes it easier to handle and dispose of. This very simple process does not create secondary waste streams, nor does it require the addition of heat. Thus, the capital equipment cost is low and there are no special environmental or safety issues associated with the process.

A2. The Envirobond™ Process

Rocky Mountain Remediation Service's patent pending Envirobond™ metals treatment process employs a combination of proprietary phosphate materials. The formulation and application may vary somewhat depending on the concentration and species of metals to be stabilized. The phosphate compounds provide electrons at the oxygen sites that form a covalent bond with the heavy metals. The metal is incorporated into the phosphate structure which has the ability to immobilize the metal and is not affected by changes in pH. Chemically, the Envirobond™ phosphates form P-O-P chains that have very little steric hindrance to internal rotation. The internal rotation of the phosphate chains allows metals to react with the negatively charged oxygen to form spiral and coiled P-O-P chains that create complex, stable metallic bonds. The result is the formation of metallic phosphates that possess stronger, longer-lasting bonds than the metal-carbonate bonds found in natural apatite stabilization compounds.

A3. Effectiveness of Envirobond™

In a treatability study conducted last year, mill tailings with high levels of arsenic, cadmium, chromium, and selenium were successfully treated (see Figure 1). In this study the waste was treated for cadmium, chromium, and selenium. Arsenic was also present at elevated levels. However, the TCLP level before treatment was not of concern, and as a result, the Envirobond™ formulation was not directed at arsenic. The results for these samples are well below the TCLP RCRA standard for all metals, and also meet the Universal Treatment Standard for all but chromium, which is 0.1 ppm above the UTS. Laboratory testing has shown that Envirobond™ is effective for other RCRA metals, extremely high levels of lead and other metals of concern such as beryllium, mercury, nickel, and zinc (see Figure 2).

A4. Cost Analysis

The cost of using Envirobond™ is significantly reduced when compared to traditional cement-based technologies. Envirobond™ can be applied using methods that range from simple agricultural type mixing (i.e., land farming) to traditional pug mill mixing. Because it can be applied in a wet or dry form, it can be adapted to many situations to reduce the cost of equipment and handling.

Treatment on-site is often very cost-effective because it avoids transportation and disposal costs. If the material can be used for fill, avoiding the cost of purchasing clean fill creates even more savings. The major disadvantage to on-site disposal is that the use of traditional cement, lime, or other similar additives will add large amounts of material to the waste, and some of these treatments are not effective enough to allow for on-site burial. Some metals such as cadmium, selenium, or zinc cannot be treated without adding large volumes of additives. With cement or lime, the heavy metals may not leach out, but they are still available to future environmental upsets because they are not permanently bound to the chemical additives. For these reasons, regulators are not willing to allow wastes to be disposed of on site, and, in many cases, have insisted that the waste be excavated and removed. With the superior results of Envirobond™, regulators will often reconsider this position.

Costs are significantly reduced when compared to cementation or excavation and hauling. With cementation, the additional bulking of the waste can easily add a 100% volume increase. The cost of materials handling and mixing is also higher. With excavation and hauling, there are additional transportation and disposal costs, and the excavated material may need to be replaced with clean fill. Figure 3 shows the savings that may result when Envirobond™ is used in place of cement-based technology. The cost per ton is greatly affected by the type of waste and by the total number of tons. Generally the cost to use Envirobond™ is $5 to $30 per ton less than cement-based products.

Figure 1. Mill Tailing Treatability Data (in ppm)

Parameter	TCLP Before Treatment	Envirobond Treated Result #1	Envirobond Treated Result #2	Envirobond Treated Result #3	Envirobond Treated Result #4	Envirobond Treated Result #5	Average of 5 Results on Original Sample	RCRA Treatment Standard	UTS Treatment Standard	Total Metals	
										Arsenic	1920
Arsenic	0.5	N/A	0.27	0.55	0.27	1.0	0.5	5	5	Barium	190
										Cadmium	27
Cadmium	0.18	0.11	0.002	<0.1	0.21	0.002	0.08	1	0.11	Chromium	570
										Lead	880
Chromium	13	0.42	0.92	.57	0.73	0.85	0.7	5	0.6	Mercury	<0.1
										Selenium	200
Selenium	1.95	0.69	0.75	1.4	0.9	0.76	0.9	5.7	5.7	Silver	<10

N/A = Not Available

Figure 2. Laboratory Results for RCRA Metals & Others

RCRA Metals	As	Ba	Cd	Lead	Nickel	Zinc	Beryllium
Total Prior to Treatment (ppm)	500	1180	27	40800	500	500	>5000
TCLP Extract Analysis (ppm)							
Sample	4.7	1.1	<0.002	<0.05	9	3	0.093
Sample	4.3	0.7	1.6	0.3	7.8	2.6	0.066
Sample		3.1	<0.002	0.12	4	1.1	
TCLP LDR Standard	5	100	1	5	N/A	N/A	N/A
Univerisal Treatment Standard	5	21	0.11	0.75	11	4.3	1.22

N/A = Not Available

Figure 3. Application Methods and Pricing

Method	Typical Envirobond Project	Traditional Cement and Silicates
Ex situ Mixing	$10-$30/ton	$30-$50/ton
In situ Landfarming	$5-25/ton	$20-$40/ton

Appendix B Case Studies

(Note: All information in this appendix was provided by the vendor, Rocky Mountain Remediation Services (RMRS). Inclusion of any information is at the discretion of RMRS, and does not necessarily constitute U.S. Environmental Protection Agency concurrence or endorsement.)

The following are case studies of sites using Envirobond™ to successfully stabilize lead, arsenic, cadmium, and other RCRA metals. The examples cited include remediation of a brownfield type of site, a former battery recycling site, and sludge from a waste water treatment site, which are typical of the types of sites where Envirobond™ has been deployed.

B1. *In situ* Treatment of Mining Waste at Former Mining Site

The effectiveness of the Envirobond™ process with mining waste and mill tailings has been superb. In addition to meeting the EPA standards for TCLP, the results of the TCLP testing have typically met the more stringent UTS. Figure 4 shows the results from a mining site in Central City, Colorado. At this site, arsenic, lead, and zinc were the contaminants of concern, exceeding the EPA's threshold level. Untreated soil was given the TCLP test, and lead and zinc exceeded the standards without treatment. Arsenic was present at 4 ppm, which is just below the RCRA standard. After treatment with Envirobond™, all three metals were below the UTS standards. The primary objective of the project was to stabilize the waste to levels that would meet the Environmental Protection Agency's (EPA) criteria for releasing the site for development. Equipment included a front-end loader, a road grader, a tractor-tiller, spreading equipment, a water truck, and a sheep's foot field compactor.

This project demonstrated the versatility of Envirobond™. Less than 4 wt. %, Envirobond™ and fly ash were added to the volume of soil, and it was mixed using field equipment. The treated soil was used to form a base for future construction. The soil was successfully layered, mixed and compacted to meet the proctor specifications for construction. The project also demonstrated that it is easy to pre-

Figure 4. On-site Full Scale *In situ* Treatment of Mine Tailings in Central City

	Arsenic	Lead	Zinc	Mercury
Total Metals (ppm)	136	1270	1270	5.9
TCLP Extract Before Treatment (ppm)	0.07	91.7	108	<0.02
TCLP Extract After Treatment (ppm)				
Sample 1	<0.05	<0.05	1.5	
Sample 2	<0.05	<0.05	1.0	
Sample 3	<0.05	<0.05	3.9	
Sample 4	<0.05	<0.05	4.5	
Sample 5	<0.05	<0.05	4.2	
Sample 6	<0.05	<0.05	4.7	
Sample 7	<0.05	<0.05	3.3	
Average	<0.05	<0.05	3.3	
TCLP Regulation CFR 261.24 (a)	5	5	NA	0.2
Current Univerisal Treatment Standard (UTS)	5	0.37	5.3	0.2

pare Envirobond™ for use in field applications. Finally, Envirobond™ does not add bulk to the waste, which is especially important when the waste is transported to a disposal facility.

Two alternatives were evaluated for remediating the site. The first was to excavate the waste piles, and other contaminated areas, and transport them to a disposal site in Denver, Colorado. There are two serious disadvantages to this alternative. The cost of transportation and disposal is high, and after the waste leaves the site, the owner remains liable for any further contamination that may occur during transportation, or at the burial site for years to come.

The second alternative was on-site treatment. The major disadvantage to this alternative was that the use of traditional cement, lime, or other similar additives will add large amounts of material to the waste, and some of these treatments are ineffective on some types of metals. Some metals such as zinc cannot be treated without adding large volumes of additives. With cement or lime, the heavy metals may not leach out, but they are still available to future environmental upsets because they are not permanently bound to the chemical additives. For these reasons, even at a higher cost, the EPA was inclined to allow only the excavation and removal of the soil.

The second alternative is much more attractive with a binder that does not add weight or volume. Use of the Envirobond™ binding agent adds less than 2 wt. % to the volume, and when combined with compaction, significantly reduces the volume. Furthermore, Envirobond™ chemically binds the metals so that they are not only physically stabilized, but they are incorporated with a chelating bond that cannot be penetrated even under severe conditions. It is not soluble, and the treated soil hardens to form a cap over the treatment area.

Costs are reduced when compared to cementation or excavation and hauling. With cementation, the additional bulking of the waste can easily add a 100% volume increase. The cost of materials handling and mixing is also higher. With excavation and hauling, there are additional transportation and disposal costs, and the excavated material would have to be replaced with clean fill dirt. All of these factors add cost that is avoided with Envirobond™.

B2. Treatment of Metals-contaminated Sludge

The Envirobond™ product can also be used to treat contaminated sludge from water treatment plants, evaporation ponds, waste treatment plants, and mining and milling operations. Typical contaminants in sludge include cadmium, lead, chromium, arsenic, aluminum, zinc, and barium. The treatment plant in this case study treats water from a mining district where the primary metals of concern are cadmium, zinc, and manganese. If the treated sludge exceeds 1 ppm cadmium, it must be shipped to a hazardous waste disposal site. The other metals are not a factor in shipping, but it is desirable to reduce them as low as possible.

The plant produces between 800 and 1400 cubic yards of 40 wt. % sludge per year. The plant uses a typical co-precipitation process that generates the sludge. In addition to the co-precipitation process, the plant treats the sludge to stabilize the cadmium to a level that will meet the RCRA TCLP standard for land disposal. (Less than 1 ppm cadmium.) Envirobond™ was successfully used to treat this sludge. The flow sheet for the process estimates the weight % of the cadmium, zinc, and manganese to be 0.017 wt.%, 1.9 wt. % and 3.64 wt. % respectively. Envirobond™ has treated the cadmium in the sludge to below 1 ppm TCLP. Significant reductions were also seen in the zinc and manganese. (To 16 ppm TCLP manganese and 255 ppm TCLP zinc). It is estimated that the cost to treat the sludge with Envirobond™ is about one-half the cost of traditional treatment.

B3. Treatment of Battery Recycle and Disposal Sites

Envirobond™ has been tested for use on two former battery sites, and is currently in use at one. In both cases, the levels of lead are similar to the high levels seen in the SITE demonstration. Those levels are often more than 90,000 ppm total, and as much as 1200 ppm after extraction using the TCLP test.

There are many sites where spent lead-acid batteries were reprocessed to recover metals. The batteries were typically cut open and sulfuric acid was allowed to drain into holding ponds. Soil contaminated by these ponds was saturated with the lead-containing acid, which accounts for the high levels present. The battery casings were then discarded and lead was recovered and smelted into ingots for reuse in the battery industry. Typical contamination around battery sites includes surface, groundwater, and soil that are contaminated with acid and extremely high concentrations of heavy metals such as lead, cadmium, and arsenic. The lead is typically very leachable due to the high acid content of the soil.

Treatment of these soils with Envirobond reduces the leachability of the lead and other metals found in contaminated soil at battery sites to the RCRA TCLP standards. The following table shows the treatability results and actual site results for a typical battery site. For this project, the soil was transported to a mixing area of about 1000 sq. ft. Approximately 1000 ton batches were mixed. The contaminated soil was layered in two layers with Envirobond reagents in the middle. Mixing was accomplished with a backhoe. The results show that excellent results were obtained, with all batches achieving the RCRA Standard of 5 ppm after TCLP testing. Figure 5 shows the results from this site.

Figure 5. Battery Recycle and Disposal Site Results

Contaminant	Total Lead (ppm)	Pretreatment TCLP (ppm)	Envirobond Treated TCLP (ppm)	RCRA Standard (ppm)
Lead (Treatability Result)	47800	956	1.97	5
Lead (Treatability Result)	74800	1160	1.47	5
Field Results (1000 ton batches)	47000	956	3.7	5
1000 tons	to 95000	to 1160	3.96	5
1000 tons			2.07	5
1000 tons			1.54	5
1000 tons			0.13	5