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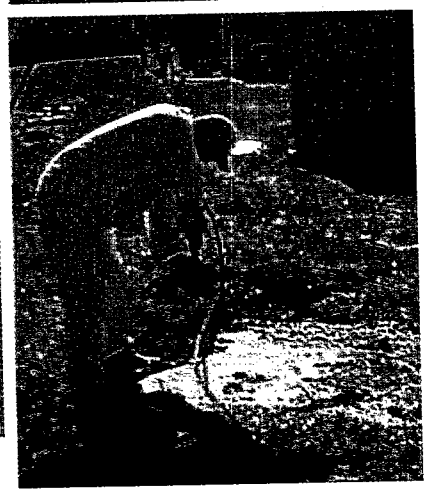
# Evaluation of Soil Amendment Technologies at the Crooksville/Roseville Pottery Area of Concern

## STAR Organics Soil Rescue

## Innovative Technology Evaluation Report



SITE
SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION

EPA/540/R-99/501
March 2003

# Evaluation of Soil Amendment Technologies at the Crooksville/Roseville Pottery Area of Concern STAR Organics Soil Rescue

## Innovative Technology Evaluation Report

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

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## Notice

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# Foreword

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

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

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.

Hugh McKinnon, Director
National Risk Management Research Laboratory

# Abstract

Star Organics, L.L.C., of Dallas, Texas (Star Organics), has developed Soil Rescue to treat soil contaminated with metals. Star Organics claims that Soil Rescue 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, Soil Rescue 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 Soil Rescue 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 Soil Rescue. The untreated and treated soil samples were analyzed for TCLP lead concentrations to evaluate whether the technology met objective PI. Analysis of the data demonstrated Soil Rescue reduced the mean TCLP lead concentration at the inactive pottery factory from 403 mg/L to 3.3 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 Soil Rescue 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 Soil Rescue. The soil samples were analyzed for soil lead bioaccessibility to evaluate whether the technology met objective P2. Analysis of the data demonstrates that Soil Rescue reduced the soil lead bioaccessibility by approximately 2.9 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.

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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 |
| µg/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 |
| Mass: | pound | kilogram | 0.454 |
| Energy | kilowatt-hour | megajoule | 3.60 |
| Power | kilowatt | horsepower | 1.34 |
| Temperature: | (° Fahrenheit - 32) | ° Celsius | 0.556 |

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 Soil Rescue 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 Soil Rescue 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 Soil Rescue.
- Secondary Objective 4 (S4) - Document the operating and design parameters of Soil Rescue.

## SITE Demonstration Results

Summarized below are the significant results of the SITE demonstration:

- Soil Rescue reduced the mean TCLP lead concentration from 403 mg/L to 3.3 mg/L, 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.
- Analysis of the data generated by application of the SIVM demonstrated that Soil Rescue reduced the soil lead bioaccessibility by approximately 2.9 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 Soil Rescue 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 Soil Rescue does not appear to exhibit long-term chemical stability.

In summary:

— Long-term soil chemical stability was indicated for soils treated by Soil Rescue at both test locations, as indicated by the analytical results of the multiple extraction procedure (MEP), pH, and cation exchange capacity (CEC) test procedures. 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 indicated at the other, by the analytical results of procedures for evaluating acid neutralization capacity, and leachable lead by the simulated precipitation leaching procedure (SPLP). The results from the procedure for evaluating lead speciation by sequential extraction indicated chemical stability inconclusively at one site, but not at all at the other. The results of tests on acid neutralization capacity 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 inconclusive, in that some soluble phases of lead were reduced, while the organic matter phase of lead was increased (organically bound lead can be released if the organic phase is biologically degraded by microbes in the soil).

— At both locations, long-term chemical stability was not indicated for soils treated by Soil Rescue, as indicated by the analytical results from oxidation-reduction (Eh) analysis, two types of total lead analyses (one using nitric and the other using hydrofluoric acid); analysis for total phosphates; and analysis for leachable phosphates by the SPLP (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).

- On the basis of information obtained from the SITE demonstration, Star Organics, and other sources, an economic analysis examined 12 cost categories for a scenario in which Soil Rescue 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 $40.27 per $yd^3$ of treated soil, which is a site-specific estimate.

## Superfund Feasibility Study Evaluation Criteria for the Soil Rescue Technology

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

**Table ES-1.** Evaluation of Soil Rescue by Application of the Nine Superfund Feasibility Study Criteria

| 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, Soil Rescue reduced the mean TCLP lead concentration from 402 mg/L to 3.3 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) lead, pH, and cation exchange capacity (CEC) 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 two types of total lead analyses, analysis for total phosphates, and analysis for SPLP phosphates. The results related to long-term effectiveness from the test for lead speciation by scanning electron microscopy and lead speciation by sequential extraction, Eh, acid neutralization and SPLP lead were inconclusive. |
| 4. | Short-term Effectiveness | Short-term effectiveness is high; 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 403 mg/L to 3.3 mg/L, reducing the mobility of the lead in the soil. |
| 6. | Implementability | The technology is relatively easy to apply. Contaminated areas can be treated with a fertilizer sprayer for treating soils to a depth of 6 inches and a pressure injection apparatus for treating depths of more than 6 inches. |
| 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 $32,500, which is $40.27 per cubic yard of soil treated. |
| 8. | Community Acceptance | Community acceptance of Soil Rescue likely will be a site-specific issue. |
| 9. | State Acceptance | State acceptance of Soil Rescue likely will be a site-specific issue. |

# Section 1
# Introduction

This section provides background information about the Superfund Innovative Technology Evaluation (SITE) Program and reports related to it; describes Soil Rescue; 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 SOIL RESCUE

Soil Rescue consists of a mixture of weak organic acids and phosphoryl esters that act as metal-complexing agents. In the complexation reaction, coordinate covalent bonds are formed among the metal ions, the organic acids and esters, and the soil substrate. Soil Rescue can be applied to the surface or pressure-injected to a depth of 15 feet into contaminated soil. If necessary, the application can be repeated until the concentrations of leachable metals in the soil are reduced to a level lower than applicable cleanup standards. In the demonstration described in this report, Soil Rescue was evaluated for effectiveness after one application.

Soil Rescue does not destroy or remove toxic concentrations of metals. Star Organics, L.L.C. (Star Organics), developer of the technology, claims that the metal complexes Soil Rescue forms immobilize the metal, reducing the concentrations of leachable metals in soil to levels that are lower than those required under applicable regulations and reducing the risks posed to human health and the environment. Star Organics claims that Soil Rescue has been designed to stabilize toxic metals in soils, sludges, and other waste streams. Star Organics claims that Soil Rescue has been effective in treating metals in soils from oil fields, such as barium and sodium, and that Soil Rescue has been tested on soils contaminated with antimony, thallium, selenium, arsenic, copper, zinc, and cadmium. Section 3.0 of this ITER presents a detailed discussion of Soil Rescue.

## 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 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 Soil Rescue 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 Soil Rescue; the needs identified by OEPA; and the goals of the SITE demonstration program, which include providing potential users of Soil Rescue 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

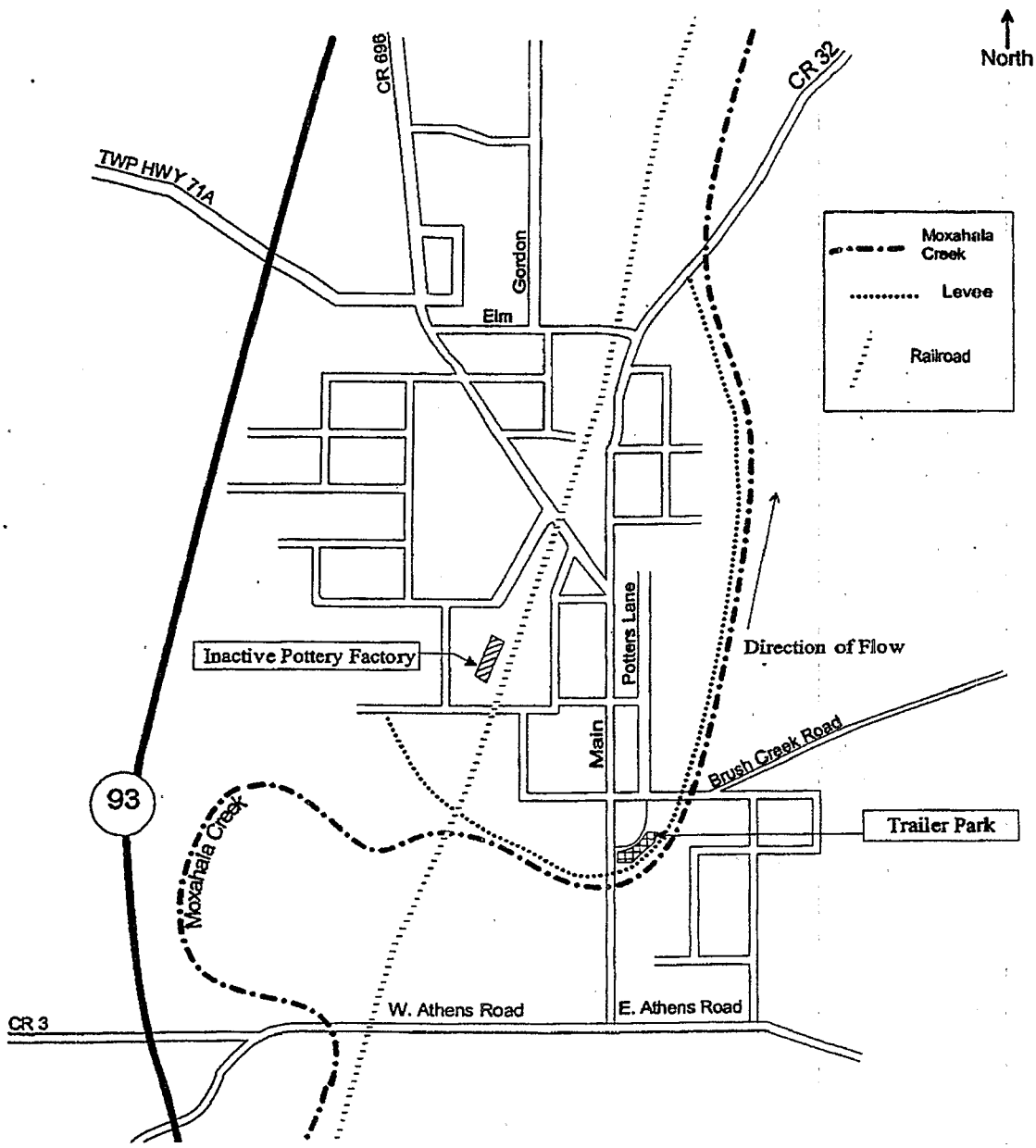



**Figure 1-1.** Location of demonstration sites in Roseville, Ohio.

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 (µg/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 Soil Rescue 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 Soil Rescue. 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 Soil Rescue 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 Soil Rescue.
- Secondary Objective 4 (S4) - Document operating and design parameters of Soil Rescue.

S1 was to determine whether Soil Rescue 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 Soil Rescue. 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 Soil Rescue 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 Soil Rescue. The cost estimates were based on observations made and data obtained during and after the demonstration, as well as data provided by Star Organics.

### *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 Soil Rescue 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, Soil Rescue, Star Organics, OEPA, and the analytical laboratories is available from the following sources:

**EPA Project Manager**
Edwin Barth
LRPCD
Office of Research and Development
U.S. Environmental Protection Agency
26 W. Martin Luther King Drive
Cincinnati, OH 45268
(513) 569-7669
(513) 569-7571 (fax)
e-mail: barth.ed@epamail.epa.gov

**EPA QA Manager**
Ann Vega
Office of Research and Development
U.S. Environmental Protection Agency
26 W. Martin Luther King Drive
Cincinnati, OH 45268
(513) 569-7635
(513) 569-7585 (fax)
e-mail: vega.ann@epamail.epa.gov

**Technology Developer**
Kevin Walsh
Star Organics, L.L.P.
3141 Hood Street
Suite 350
Dallas, TX 75219
(214) 522-0742, ext. 122
(214) 522-0616 (fax)
e-mail: kwalsh5@hotmail.com

**Tetra Tech Project Manager**
Mark Evans
Tetra Tech EM Inc.
1881 Campus Commons Drive, Suite 200
Reston, VA 20191
(703)390-0637
(703) 391-5876 (fax)
e-mail: evansm@ttemi.com

**Tetra Tech QA Manager**
Greg Swanson

Tetra Tech EM Inc.
591 Camino de la Reina, Suite 640
San Diego, CA 92108
(619) 718-9676
(619) 718-9698 (fax)
e-mail: swansog@ttemi.com

**Analytical Laboratory Managers**
Jamie McKinney
Quanterra Analytical Services
5815 Middlebrook Pike
Knoxville, TN 37921
(423) 588-6401
(423) 584-4315 (fax)
e-mail: mckinney@quanterra.com

John Drexler
Department of Geology
University of Colorado
2200 Colorado Avenue
Boulder, CO 80309
(303) 492-5251
(303) 492-2606 (fax)
e-mail: drexlerj@spot.colorado.edu

David Germeroth
Maxim Technologies, Inc.
1908 Innerbelt Business Center Drive
St. Louis, MO 63114-5700
(314) 426-0880
(314) 426-4212 (fax)
e-mail: dgermero.stlouis@maximmail.com

Steve Hall
Kiber Environmental Services
3145 Medlock Bridge Road
Norcross, GA 30071
(770) 242-4090, ext. 285
(770) 242-9198 (fax)
e-mail: stevehall@kiber.com

Rob Liversage
Data Chem Laboratory
4388 Glendale-Milford Road
Cincinnati, OH 45242
(513) 733-5336
(513) 733-5347 (fax)
e-mail: rob@datachemlabs.com

**Ohio EPA**
Abby Lavelle
Southeast District Office
Ohio Environmental Protection Agency
2195 Front Street
Logan, OH 43139-9031
(740) 380-5296

# Section 2
# Technology Effectiveness Analysis

This section addresses the effectiveness of Soil Rescue 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 Soil Rescue 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

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

| Site Name and Location | Maximum Lead Concentrations[1] | | | | |
|---|---|---|---|---|---|
| | 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.

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 Soil Rescue, 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.

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

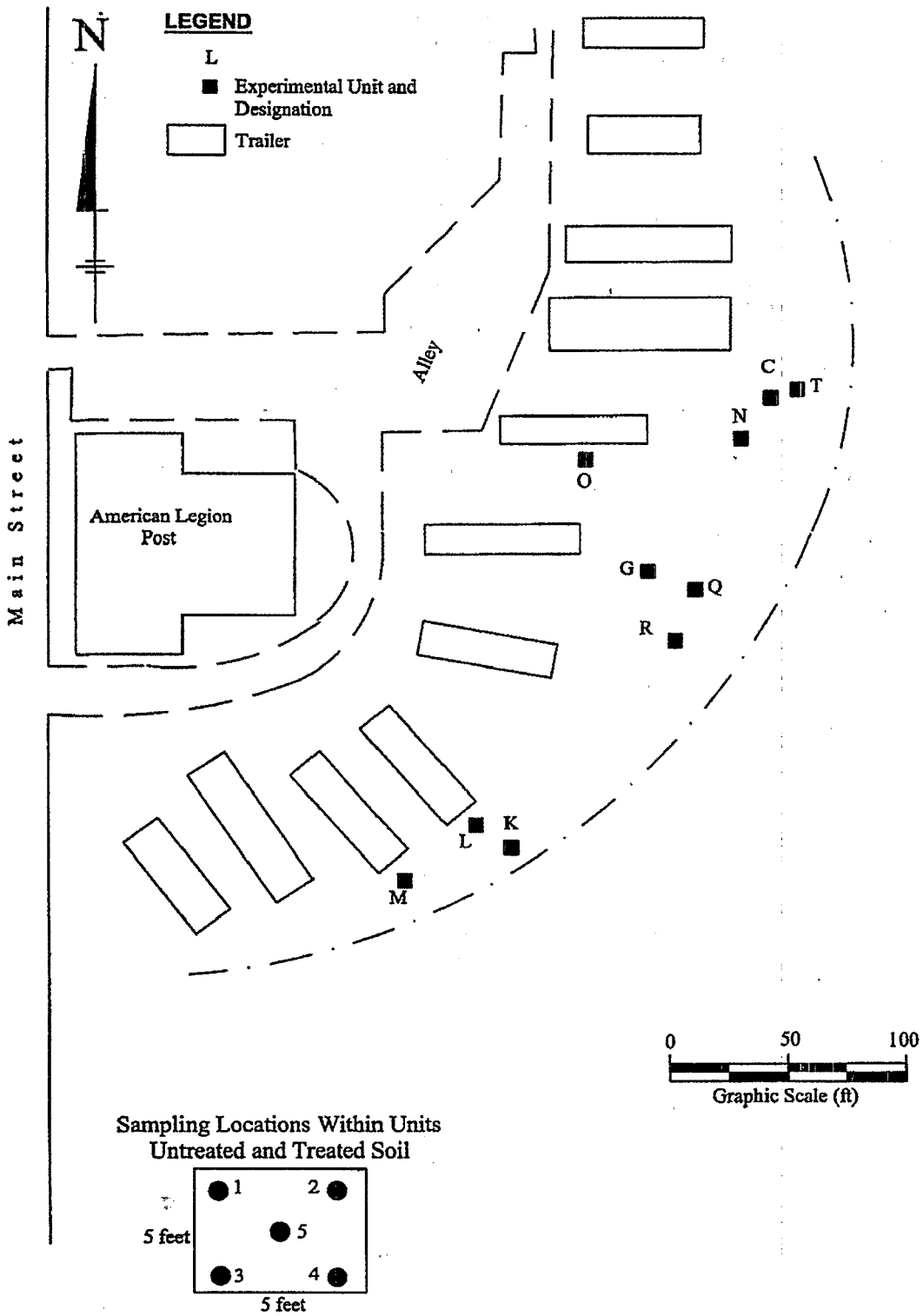
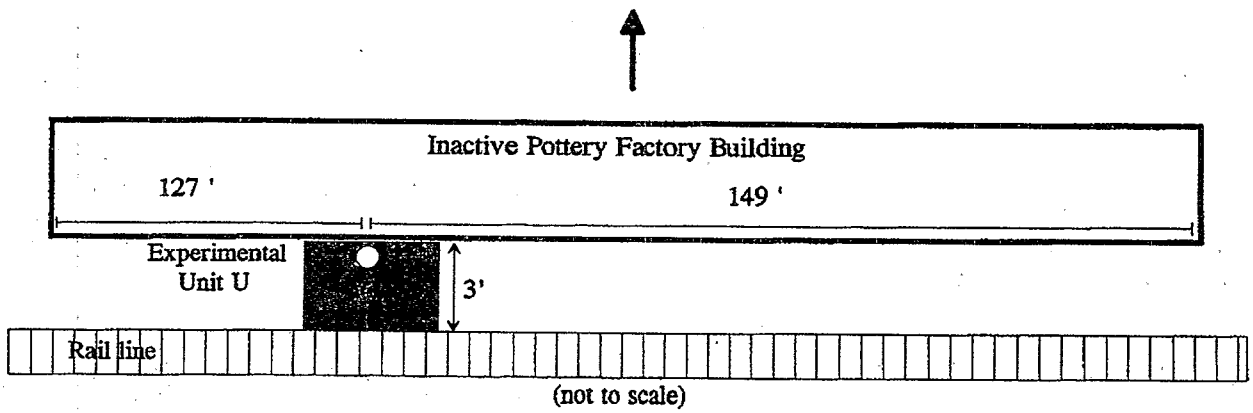
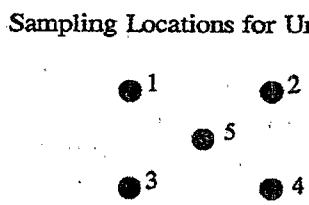
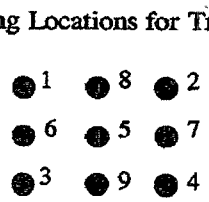



**Figure 2-1.** Trailer park sampling locations and patterns.



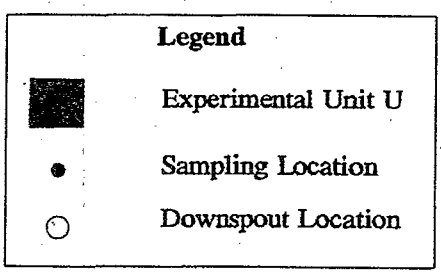




**Figure 2-2.** Inactive pottery factory sampling locations and patterns.

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

After completing the activities described in Section 2.2.1, Star Organics, using a pressurized wand, applied Soil Rescue to the soil in each experimental unit to a depth of two feet.

### 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 Soil Rescue after a minimum of 72 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 collected, 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.

**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 BaCl2 Method |
| Acid Neutralization Capacity | Soil | Environment Canada Method No. 7 | Acid Neutralization Capacity |
| Total Lead using Nitric Acid Digestion | 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) |
| 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 |

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° C for one hour, using a modified TCLP apparatus
- 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

**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 |

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 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 2EC 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 after 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 μm, 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:

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

where *xti* and *xui* represent the *ith* observations about treated and untreated soils, *n* represents the sample size, *yi* represents the calculated difference between the *ith* observations, *ym* represents the arithmetic mean of the calculated differences, and $Sy^2$ represents the calculated variance.

The calculation results in the following t-test statistic:

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

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-r0 ) percent reduction in the arithmetic mean contaminant levels between normally distributed (paired) data on treated and untreated soils for P2 was:

$$\hat{C}_R = C_T - C_U(1 - r_0)\ \text{ where }\ C_T = \sum_{i=1}^{n} x_{th}/n\ \text{ and }\ C_U = \sum_{i=1}^{n} x_{uh}/n$$

where *xth* and *xuh* 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 $C_R$ represents the computed test statistic. The variance for the estimate was calculated as follows:

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

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:

$$y_i = x_{ti} - (1 - r_0)x_{ui}\ ,\quad y_m = \sum_{i=1}^{n} y_i / n\ ,\ \text{and}\ \ S_y^2 = \sum_{i=1}^{n} (y_i - y_m)^2 / (n-1)$$

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

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

That calculation resulted in the following t-test statistic:

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

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

**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 Soil Rescue 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 Soil Rescue. | 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 Soil Rescue. | Cost analyses | Present cost data/No specific acceptance criteria were established for S4. |

Notes:
[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.

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:

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

where *xti* and *xui* once again represent the *ith* 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 Soil Rescue 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 0.005 (or 1 in 500) that the actual mean concentration of TCLP lead in the treated soils is higher than 7.5 mg/L. Therefore, it was concluded that Soil Rescue achieved the first primary objective (P1) of the SITE demonstration. In addition, Soil Rescue 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 on a formal statistical basis; however, concentrations of TCLP lead were measured in untreated and treated soil at 3 of the 10 experimental units at that location. The analytical results for TCLP lead from two of those experimental units indicate similar reductions in concentrations of TCLP lead. No reductions in concentrations of TCLP lead could be identified for samples collected at the third experimental unit, because the concentrations of TCLP lead in both untreated and treated soils from that unit were lower than detection limits. Table 2-7 summarizes the TCLP lead results from the trailer park.

**Table 2-5.** TCLP Lead Results for the Inactive Pottery Factory Site

| Experimental Unit | Sampling Location | Untreated (mg/L) | Treated (mg/L) |
|---|---|---|---|
| U | 1 | 453 | 3.2 |
| U | 2 | 376 | 3.0 |
| U | 3 | 411 | 3.6 |
| U | 4 | 364 | 3.5 |
| U | 5 | 411 | 3.1 |
| U | 6 | n/s | 4.0 |
| U | 7 | n/s | 2.9 |
| U | 8 | n/s | 3.2 |
| U | 9 | n/s | 3.2 |

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) |
|---|---|---|---|---|
| 403 | 3.3 | 99% | 3.484 | <0.005 |

## 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 2-8 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 2-7.** TCLP Lead Results for the Trailer Park Site

| Experimental Unit | Sampling Location | Untreated (mg/L) | Treated (mg/L) |
|---|---|---|---|
| G | Comp | 13.2 | 1.3 |
| L | Comp | 11.9 | 1.4 |
| T | Comp | <0.50 | <0.50 |

Note: Comp = Composite of five sampling locations within an experimental unit (see Figure 2-1).

**Table 2-8.** Soil Lead Bioaccessibility Results

| | Untreated Results | | | Treated Results | | | Summary |
|---|---|---|---|---|---|---|---|
| Unit | Total Lead (mg/kg) | Bioaccessible Lead (mg/kg) | Percentage Lead | Total Lead (mg/kg) | Bioaccessible Lead (mg/kg) | Percentage Lead | Percent Reduction |
| C | 645.97 | 325.29 | 50.4% | 587.41 | 259.79 | 44.2% | 12.2% |
| G | 6446.73 | 4536.05 | 70.4% | 8751.09 | 6025.50 | 68.9% | 2.1% |
| K | 2394.56 | 1378.70 | 57.6% | 2525.71 | 1617.51 | 64.1% | -11.2% |
| L | 7775.47 | 5209.88 | 67.0% | 7255.24 | 4780.36 | 65.9% | 1.7% |
| M | 2941.40 | 1714.58 | 58.3% | 2862.71 | 1807.93 | 63.2% | -8.3% |
| N | 2303.51 | 1338.74 | 58.1% | 1680.93 | 953.83 | 56.8% | 2.4% |
| O | 2378.06 | 1140.08 | 47.9% | 2980.51 | 1553.04 | 52.1% | -8.7% |
| Q | 726.82 | 381.79 | 52.5% | 824.93 | 344.46 | 41.8% | 20.5% |
| R | 1406.92 | 649.48 | 46.2% | 1397.99 | 699.90 | 50.1% | -8.5% |
| T | 339.34 | 148.68 | 43.8% | 348.95 | 113.34 | 32.5% | 25.9% |

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-r0)% reduction in the arithmetic mean was used, with r0 equal to 0.25. Table 2-9 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 Soil Rescue soil lead bioaccessibility data. Table 2-10 summarizes the results of that analysis.

The calculated percent reduction in soil lead bioaccessibility was 2.92 percent, with a calculated standard deviation of 3.99 percent and a 95 percent confidence interval of -4.8 percent to 11.2 percent. None 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 Soil Rescue 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 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

**Table 2-9.** Parametric Test Statistics, Soil Lead Bioaccessibility Data

| Statistic | Data |
|---|---|
| Value of $C_R$[1] | 12.53% |
| Standard deviation | 7.2 |
| t-score ($H_o$: $C_R$ greater than or equal to 0) | 5.499 |
| Level of significance | 0.9999 |

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

**Table 2-10.** Bootstrap Statistical Results for Bioavailable Lead Difference Data

| Statistic | Data |
|---|---|
| Mean | 2.92% |
| Standard deviation | 3.99% |
| 95% confidence interval | (-4.8%, 11.2%) |
| Number of percent reduction samples > 25% | 0/1,000 |

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 2-11 lists the analytical results for the MEP. The data on untreated soil from experimental unit G at the trailer park indicated that the analytical results for the MEP exceeded 5.0 mg/L for days 5 and 6 of the 11-day extraction period. The data on treated soil from the trailer park indicated that the MEP analytical results were consistently less than 5.0 mg/L for the extraction period. Figure 2-3 shows the MEP results for the sample of untreated soil from unit G that were higher than or equal to 5.0 mg/L with the corresponding results for treated soils.

For the five sampling locations at the inactive pottery factory, results for samples of untreated soil were higher than or equal to 5.0 mg/L. The data on treated soil from the inactive pottery factory indicated that the analytical results for the MEP were consistently less than 5.0 mg/L for the extraction period. Figures 2-4 through 2-8 show the results for the samples of untreated soil from the inactive pottery factory that were higher than or equal to 5.0 mg/L, with the corresponding results for treated soil.

On days 7 or 8, the extractions are repeated until concentrations decrease, or until Day 12. Results for Days 10 to 12 were not recorded if there was no increase in lead concentrations from Days 7 or 8 to Day 9.

The analytical results for the MEP indicate that the lead did not leach from the soil treated with Soil Rescue under repetitive precipitation of acid rain conditions. Therefore, the long-term chemical stability of the treated soil, as measured by the MEP, appears to have been enhanced by the addition of Soil Rescue.

## 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 Soil Rescue 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 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 2-12 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 5 of the 18 phases that were evaluated. The frequency of the lead phosphate phase, and possibly the glass phase, increased between the values for untreated and treated soils, a condition that would be indicative of an

**Table 2-11.** 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) | Day 11 (mg/L) | Day 12 (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trailer Park | | | | | | | | | | | | | | |
| C | Untreated | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | 0.095 | 0.064 | 0.087 | <0.050 | | | |
| C | Treated | 0.21 | 0.12 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | | | |
| G | Untreated | 1.8 | 0.38 | 0.11 | 0.15 | 0.057 | 20 | 7.4 | 3.9 | 2.3 | 3.3 | 3.9 | 2.8 | |
| G | Treated | 0.61 | 0.62 | 0.98 | 0.52 | 0.24 | 0.078 | 0.22 | 0.27 | 0.34 | 0.14 | | | |
| K | Untreated | 0.18 | 0.11 | 0.14 | 0.067 | <0.050 | 0.64 | 1.7 | 0.62 | 1.3 | 0.49 | | | |
| K | Treated | 0.97 | 0.4 | 0.33 | 0.21 | 0.065 | 0.057 | 0.25 | 0.33 | 0.33 | 0.32 | | | |
| L | Untreated | 0.55 | 0.19 | 0.25 | 0.21 | 0.12 | 0.12 | 0.072 | 0.11 | 0.11 | <0.050 | | | |
| L | Treated | 0.65 | 0.81 | 0.58 | 0.38 | 0.15 | 0.076 | <0.050 | 0.06 | 0.12 | 0.12 | 0.29 | 0.6 | 0.22 |
| M | Untreated | 1.3 | <0.050 | 0.22 | 0.11 | 0.063 | 0.12 | <0.050 | <0.050 | 0.38 | 0.056 | | | |
| M | Treated | 0.61 | 0.37 | 0.48 | 0.26 | 0.1 | <0.050 | <0.050 | <0.050 | 0.06 | <0.050 | | | |
| N | Untreated | 0.11 | 0.12 | 0.12 | <0.050 | <0.050 | 0.088 | 0.2 | 0.11 | 0.6 | 0.099 | | | |
| N | Treated | 0.91 | 0.43 | 0.25 | 0.11 | 0.072 | <0.050 | 0.06 | <0.050 | 0.061 | 0.06 | | | |
| O | Untreated | 0.16 | 0.075 | 0.11 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | 0.3 | <0.050 | | | |
| O | Treated | 0.2 | 0.13 | 0.087 | 0.23 | 0.091 | 0.1 | 0.11 | 0.92 | 0.059 | <0.050 | | | |
| Q | Untreated | <0.050 | 0.062 | <0.050 | <0.050 | <0.050 | 0.077 | 0.21 | 0.075 | 0.22 | <0.050 | | | |
| Q | Treated | 0.09 | 0.061 | 0.071 | 0.064 | <0.050 | <0.050 | <0.050 | 1.5 | <0.050 | <0.050 | | | |
| Q (Duplicate) | Untreated | 0.075 | <0.050 | <0.050 | <0.050 | <0.050 | 0.28 | 0.36 | <0.050 | 0.28 | 0.09 | | | |
| Q (Duplicate) | Treated | 0.078 | 0.081 | <0.050 | 0.061 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | | | |
| R | Untreated | 0.1 | 0.09 | 0.086 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | <0.050 | 0.094 | 0.22 | 0.14 | |
| R | Treated | 0.39 | 0.2 | 0.15 | 0.057 | <0.050 | 0.057 | 0.058 | 0.073 | 0.095 | 0.092 | | | |

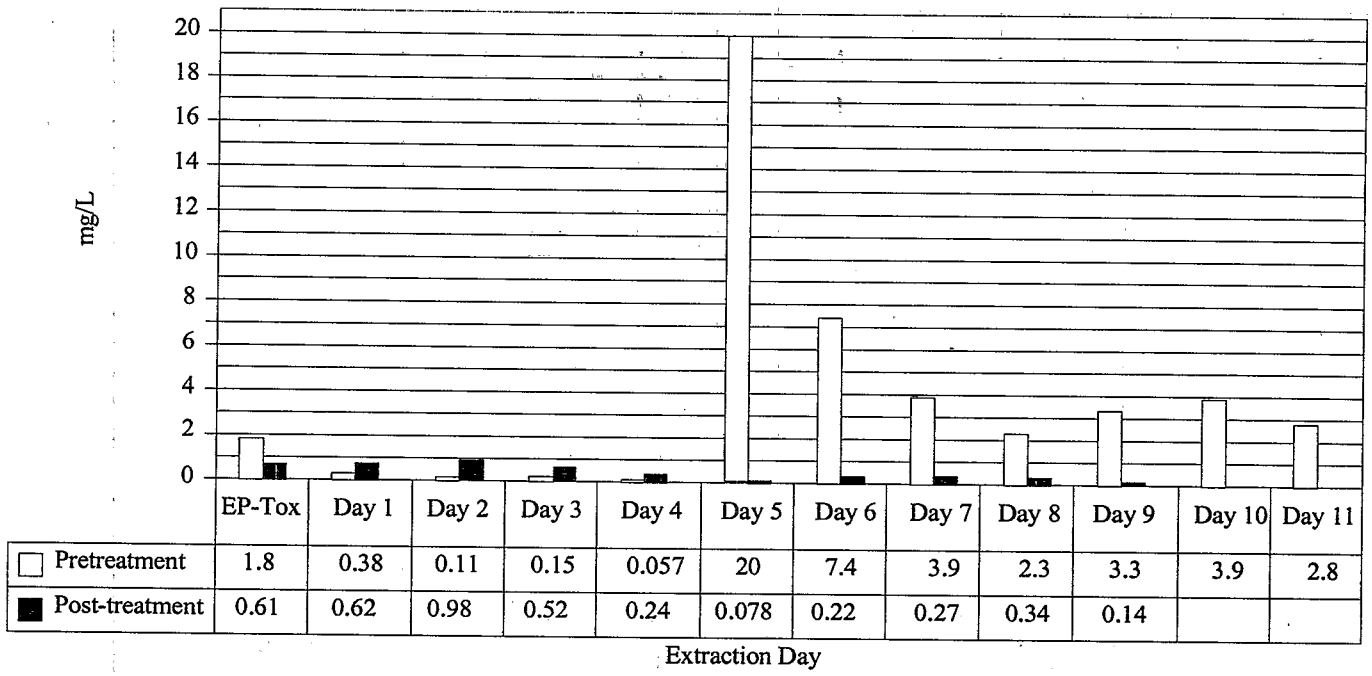
Note: [1]After the initial daily extract, nine extractions are performed on each of the following nine days; if the lead concentration is higher in Day 9 than the concentrations in Days 7 or 8, the extractions are repeated until concentrations decrease, or until Day 12. Results for Days 10 to 12 were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

(continued)

**Table 2-11.** MEP Analytical Results (continued)

| 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) | Day 11 (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trailer Park | | | | | | | | | | | | | |
| T | Untreated | <0.050 | <0.050 | 0.051 | <0.050 | 0.11 | 0.14 | 0.45 | 0.26 | 0.33 | <0.050 | | |
| T | Treated | <0.050 | <0.050 | 0.1 | <0.050 | <0.050 | <0.050 | <0.050 | 1.1 | <0.050 | <0.050 | | |
| Inactive Pottery Factory | | | | | | | | | | | | | |
| U Location 1 | Untreated | 640 | 280 | 120 | 21 | 0.14 | 0.097 | 0.13 | 0.21 | 0.64 | 0.89 | 5.5 | 0.67 |
| U Location 1 | Treated | 1.1 | 1.3 | 2.3 | 2.4 | 3.3 | 2.4 | 0.99 | 0.86 | 0.87 | 0.72 | | |
| U Location 2 | Untreated | 450 | 150 | 57 | 7.6 | 0.18 | 0.24 | 0.11 | 0.13 | 0.097 | 0.077 | | |
| U Location 2 | Treated | 1 | 2.2 | 2.1 | 2 | 2.7 | 2.2 | 0.87 | 0.81 | 0.8 | 0.12 | 0.58 | |
| U Location 3 | Untreated | 260 | 3.7 | 0.08 | 0.31 | 0.39 | 0.16 | 0.15 | 0.29 | 0.18 | 0.14 | | |
| U Location 3 | Treated | 1.1 | 1.9 | 2.2 | 3.5 | 3.5 | 2.1 | 1.1 | 1 | 0.9 | 0.65 | | |
| U Location 4 | Untreated | 203 | 7.1 | 0.61 | 0.26 | 0.45 | 0.15 | 0.12 | 0.2 | 0.21 | 0.18 | | |
| U Location 4 | Treated | 1.1 | 2.9 | 2.2 | 2.1 | 3.8 | 2.9 | 0.88 | 0.85 | 0.81 | 0.69 | | |
| U Location 5 | Untreated | 290 | 78 | 2.6 | 0.39 | 0.52 | 0.66 | 1.7 | 2.9 | 2.2 | 0.84 | | |
| U Location 5 | Treated | 1 | 1.6 | 2.5 | 3.2 | 3.5 | 2.8 | 0.94 | 0.8 | 1.1 | 1.2 | 0.51 | |
| U Location 6 | Treated | 1.2 | 0.5 | 1.5 | 1.7 | 2.8 | 2 | 0.68 | 0.79 | 0.71 | 0.55 | | |
| U Location 7 | Treated | 0.97 | 2.1 | 1.9 | 2.5 | 2.6 | 2.5 | 0.92 | 0.72 | 0.81 | 0.82 | 0.53 | |
| U Location 8 | Treated | 1 | 1.8 | 1.8 | 1.9 | 2.8 | 2.3 | 0.88 | 0.64 | 0.93 | 0.8 | 0.36 | |
| U Location 9 | Treated | 1.2 | 1.5 | 1.9 | 2.7 | 5.1 | 3.3 | 0.72 | 0.9 | 1.6 | 1.1 | 0.64 | |

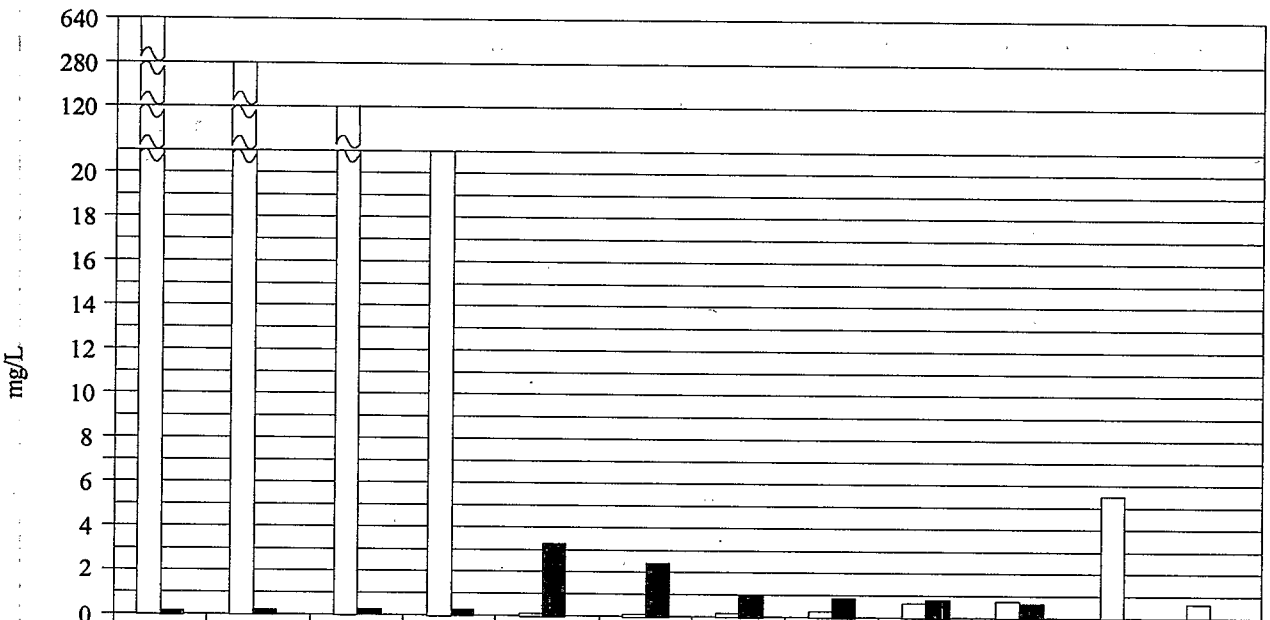
Note: [1]After the initial daily extract, nine extractions are performed on each of the following nine days; if the lead concentration is higher in Day 9 than the concentrations in Days 7 or 8, the extractions are repeated until concentrations decrease, or until Day 12. Results for Days 10 to 12 were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




| | EP-Tox | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 | Day 8 | Day 9 | Day 10 | Day 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pretreatment | 1.8 | 0.38 | 0.11 | 0.15 | 0.057 | 20 | 7.4 | 3.9 | 2.3 | 3.3 | 3.9 | 2.8 |
| Post-treatment | 0.61 | 0.62 | 0.98 | 0.52 | 0.24 | 0.078 | 0.22 | 0.27 | 0.34 | 0.14 | | |

Extraction Day

**Figure 2-3.** MEP lead results for experimental unit G at the trailer park.




| | EP-Tox | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 | Day 8 | Day 9 | Day 10 | Day 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pretreatment | 640 | 280 | 120 | 21 | 0.14 | 0.097 | 0.13 | 0.21 | 0.64 | 0.89 | 5.5 | 0.67 |
| Post-treatment | 1.1 | 1.3 | 2.3 | 2.4 | 3.3 | 2.4 | 0.99 | 0.86 | 0.87 | 0.72 | | |

Extraction Day

**Figure 2-4.** MEP lead results for sampling location 1 at the inactive pottery factory.

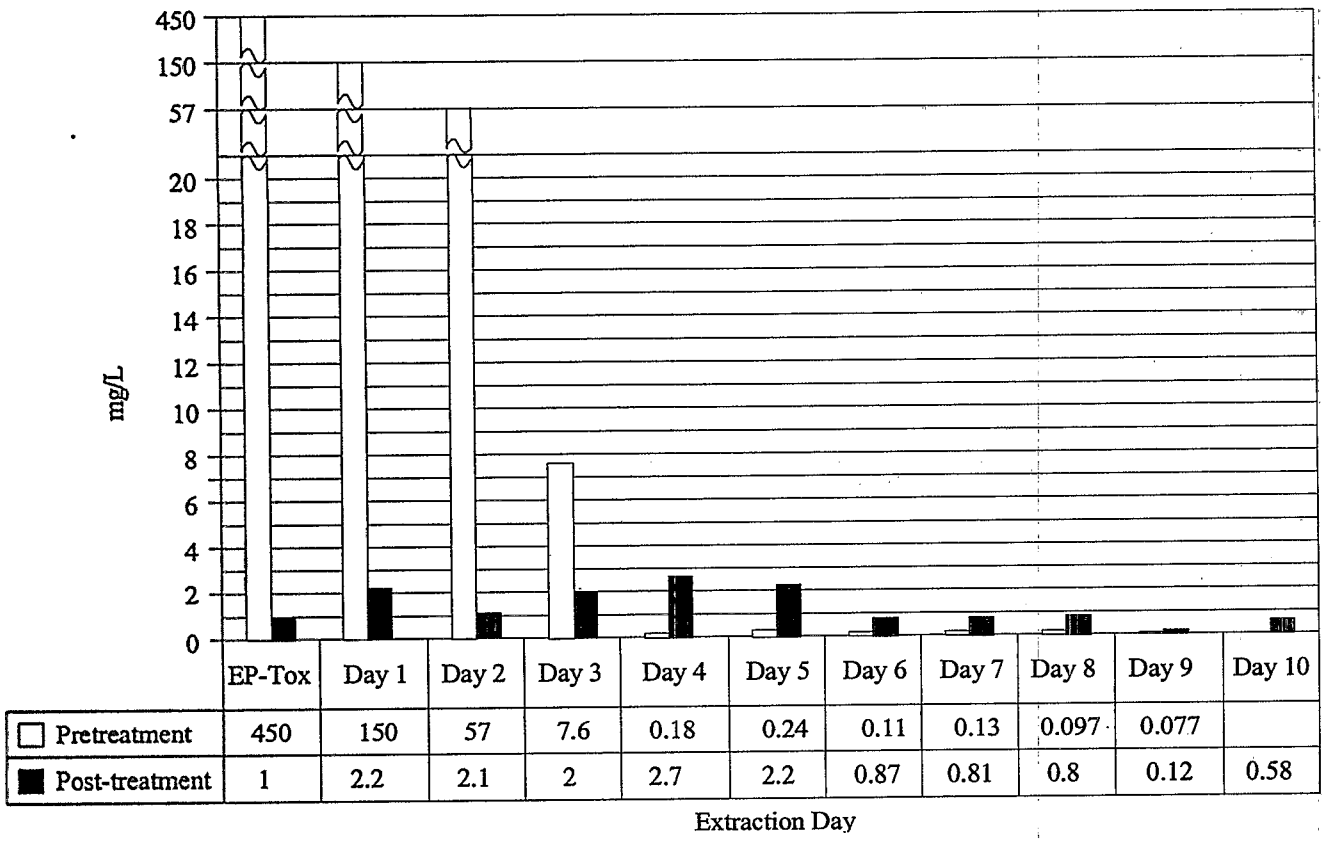



**Figure 2-5.** MEP lead results for sampling location 2 at the inactive pottery factory.

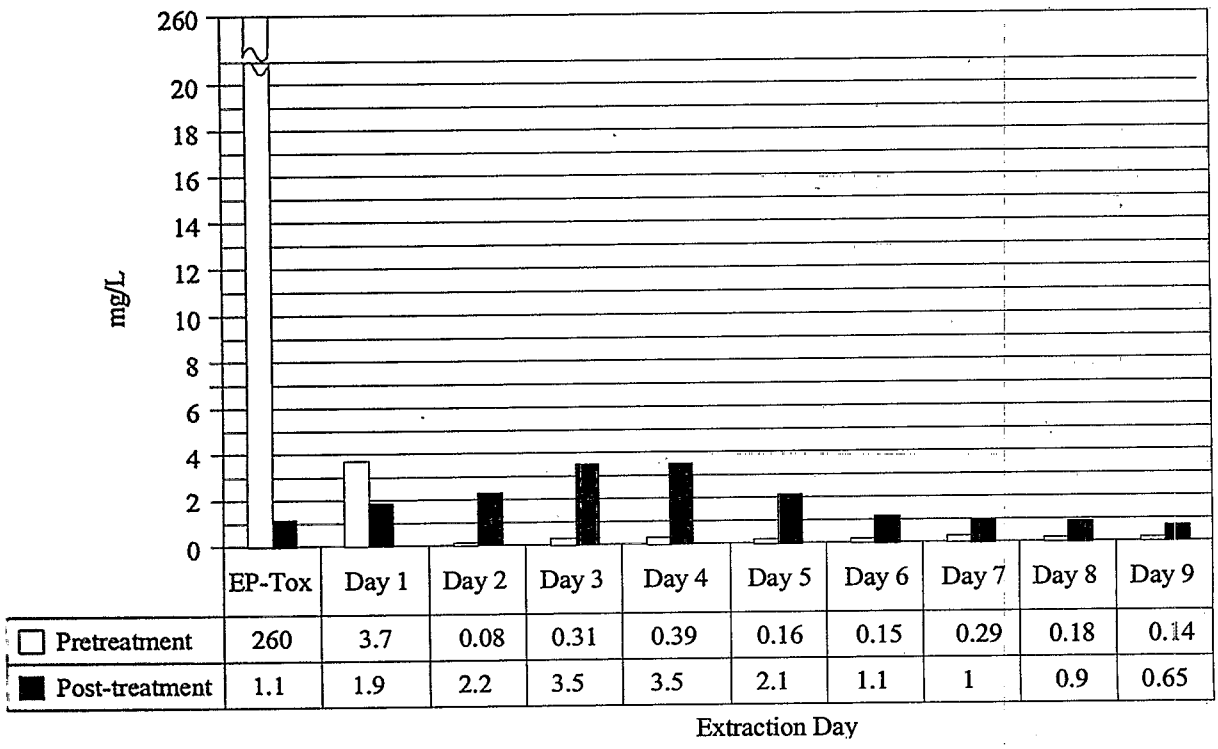
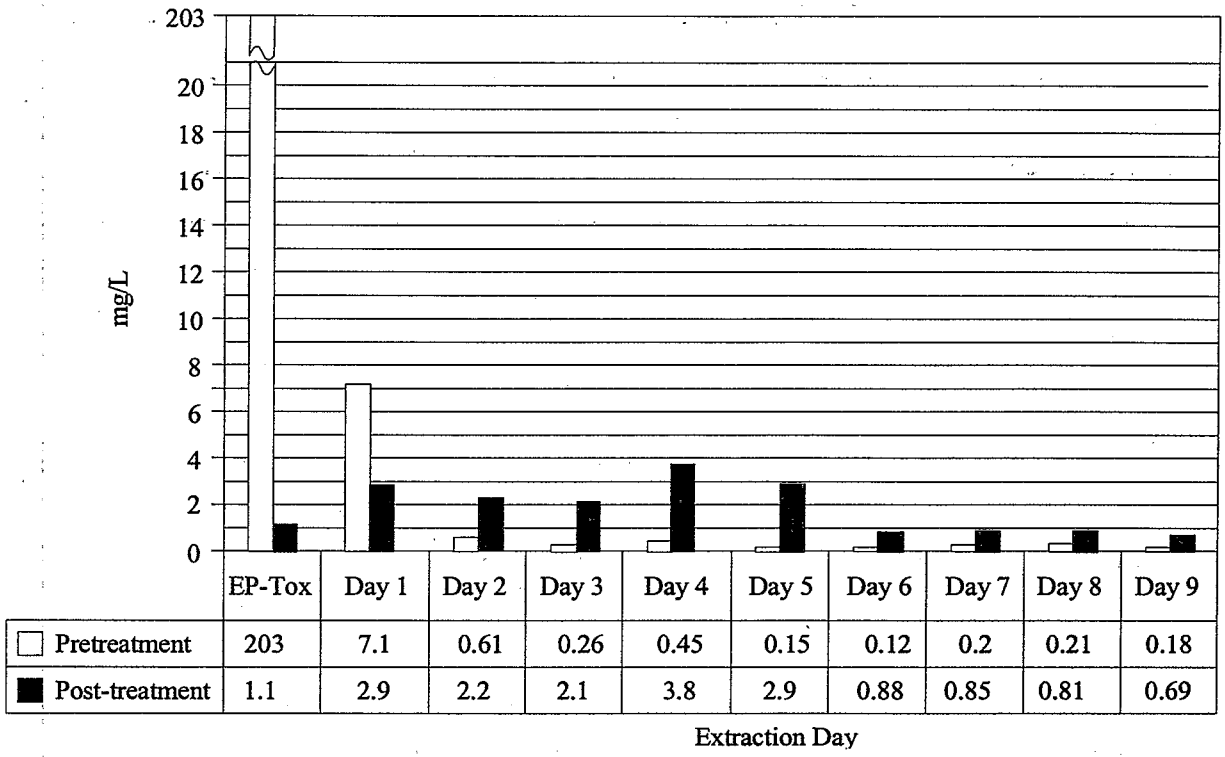
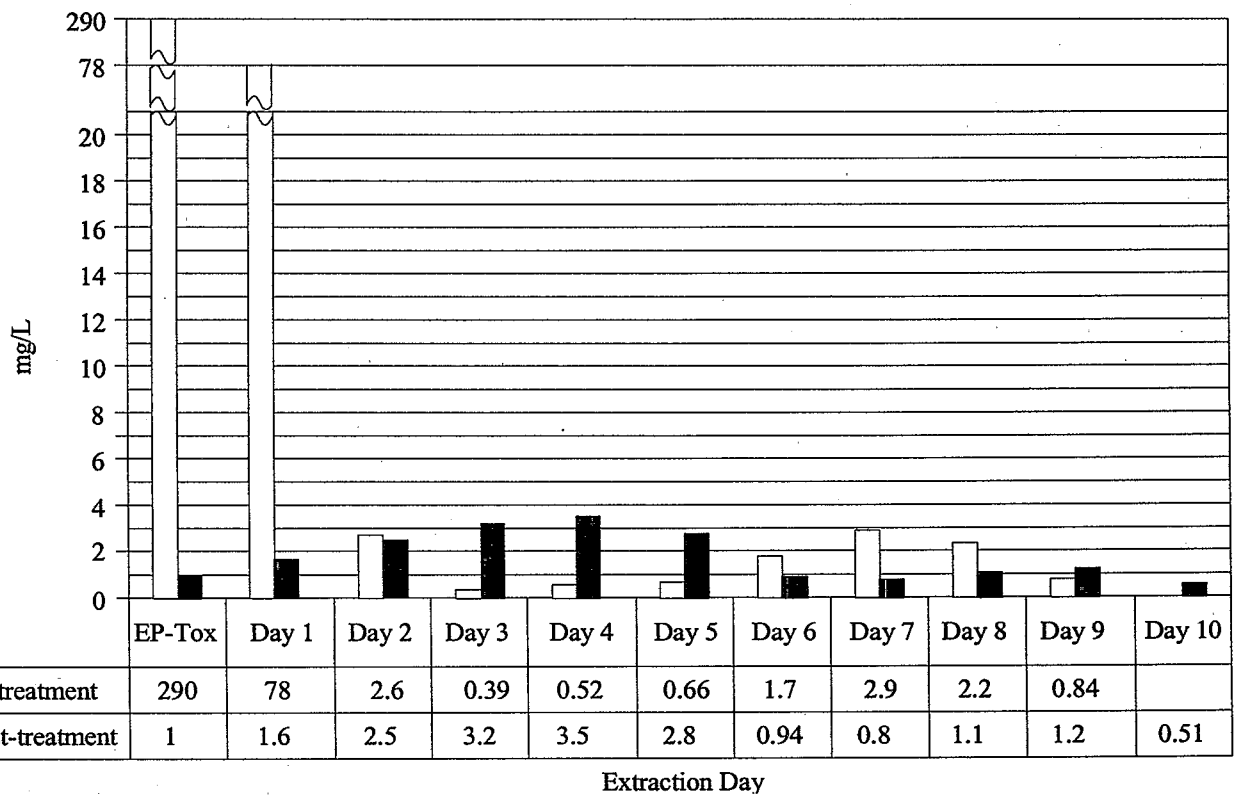



**Figure 2-6.** MEP lead results for sampling location 3 at the inactive pottery factory.




| | EP-Tox | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 | Day 8 | Day 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Pretreatment | 203 | 7.1 | 0.61 | 0.26 | 0.45 | 0.15 | 0.12 | 0.2 | 0.21 | 0.18 |
| Post-treatment | 1.1 | 2.9 | 2.2 | 2.1 | 3.8 | 2.9 | 0.88 | 0.85 | 0.81 | 0.69 |

**Figure 2-7.** MEP lead results for sampling location 4 at the inactive pottery factory.




| | EP-Tox | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 | Day 8 | Day 9 | Day 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pretreatment | 290 | 78 | 2.6 | 0.39 | 0.52 | 0.66 | 1.7 | 2.9 | 2.2 | 0.84 | |
| Post-treatment | 1 | 1.6 | 2.5 | 3.2 | 3.5 | 2.8 | 0.94 | 0.8 | 1.1 | 1.2 | 0.51 |

**Figure 2-8.** MEP lead results for sampling location 5 at the inactive pottery factory.

**Table 2-12.** 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 | 0.02 | nc[1] | 9 | 0.01 | nc | 9 |
| Barite | 0.1 | nc | 8 | 1 | nc | 6 |
| Brass | 0 | nc | 10 | 0.13 | nc | 8 |
| Cerussite | 0.41 | 1.2 | 8 | 0.67 | 1.7 | 4 |
| Clay | 0 | nc | 10 | 0 | nc | 10 |
| Fe-Oxide[2] | 44.77 | 15.09 | 0 | 21.09 | 14.47 | 0 |
| Fe-Pb Sulfate | 0.17 | nc | 7 | 0 | nc | 10 |
| Galena | 0 | nc | 10 | 0 | nc | 10 |
| Glass[2] | 39.11 | 16.15 | 0 | 52.52 | 20.55 | 0 |
| Mn-Oxide[2] | 8.39 | 11.25 | 3 | 2.46 | 5.63 | 7 |
| Organic[2] | 1.88 | 4.55 | 7 | 12.23 | 16.36 | 3 |
| Pb Vanadate | 0 | nc | 10 | 0.01 | nc | 9 |
| PbMO | 1.93 | 1.08 | 0 | 1.52 | 1.07 | 0 |
| $PbSiO_2$ | 0.58 | 1.37 | 6 | 1.51 | 2.64 | 3 |
| Phosphate[2] | 0.09 | 0.19 | 8 | 5.2 | 4.58 | 1 |
| Si-Phosphate | 0 | nc | 10 | 0.07 | nc | 9 |
| Slag | 2.28 | nc | 5 | 1.86 | nc | 6 |
| Solder | 0.02 | nc | 9 | 0.04 | nc | 8 |

[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.

increase in the long-term chemical stability of the soil. Also indicative of chemical stability are the apparent reductions in the iron oxide and manganese oxide phases of lead. The results also indicate that there was an increase in the organic lead phase, which indicates a reduction in stability from the untreated to the treated soils. Application of Soil Rescue appears to increase the organic lead phase; however, it also appears to increase the less-soluble phosphate phase and reduce the soluble oxide phases of lead in the treated soil. 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 five phases. Therefore, the lead speciation results were not unanimously consistent with the attainment of objective S1; however, it appears that those results suggest that Soil Rescue 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 2-13 and Table 2-14 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 2-15 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 the corresponding level of significance is less than $0.05/6 = 0.0083$.

As Table 2-15 shows, the results of the sequential serial soil extractions indicate reductions in the concentrations of four of the six lead phases (exchangeable, carbonate, manganese oxide, and iron oxide) and increases in the other two lead phases (organic matter and residual) in soils from both sites. Those results are consistent with those obtained for lead speciation by the SEM procedure (presented in the previous section).

Of the results for the 12 Student t-tests, 8 appear to be statistically significant. The four other results were almost statistically significant; therefore, the changes in the treated soils that these other four tests indicated probably occurred. The four results that were not found to be significant at the 0.05 level of significance include increases in exchangeable and organic matter phases at the trailer park and increases in residual concentrations at both locations. There are significant decreases in the mean concentrations of lead bound to carbonates and lead bound to iron and manganese oxide phases at both sites. Soil from the trailer park also exhibited a significant decrease in lead bound to the exchangeable phase. Soil from the inactive pottery factory exhibited a significant increase in the organic matter phase.

The results of the statistical analysis indicate that Soil Rescue increased the mean concentrations of the residual phases of lead at both site locations; however, such increases do not appear to be significant at the 0.05 level of significance. Those results also indicate that the application of Soil Rescue significantly reduced the concentrations of three soluble lead phases (carbonate, manganese oxide, and iron oxide) at both sites, with significant and almost-significant reductions of another highly soluble lead phase (exchangeable). Finally, the data indicate that significant and almost-significant increases of another soluble lead phase (organic matter) occurred at both locations. Therefore, the lead speciation results were not unanimously consistent with the attainment of objective S1.

## 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 2-16 presents the Eh data for untreated and treated soil from the trailer park, and Table 2-17 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 2-18 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 increase in the Eh mean level from the untreated to the treated soil appears to be statistically significant. The Eh results from the trailer park therefore indicate that the application of Soil Rescue has increased the Eh of the soil, which does not indicate long-term stability of the soil treated with Soil Rescue at the trailer park. For the soil from the inactive pottery factory, the decrease in the Eh mean from the untreated to the treated soil appears not to be significant and therefore would not indicate long-term

**Table 2-13.** Sequential Serial Soil Extracts Results, Trailer Park

| Unit | Sampling Location | Untreated | | | | | | Treated | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 |
| C | Comp | 3.46 | 2.65 | 1.657 | 6.19 | 7.29 | 187 | 0.13 | 9.35 | 0.103 | 2.27 | 9.99 | 381 |
| G | Comp | 80.4 | 81.42 | 23.25 | 62.5 | 61.75 | 2026 | 3.62 | 22.72 | 8.935 | 46.62 | 245.5 | 4,064 |
| K | Comp | 37.5 | 36.66 | 6.985 | 30.22 | 15.44 | 781 | 3.03 | 7.92 | 5.131 | 20.64 | 52.23 | 2,583 |
| L | Comp | 60.9 | 105.4 | 9.039 | 88.69 | 42.98 | 2386 | 15.14 | 57.48 | 3.949 | 81.28 | 125.1 | 3,903 |
| M | Comp | 11 | 70.49 | 15.97 | 32.64 | 14.96 | 543 | 6.53 | 18.37 | 12.4 | 31.92 | 33.23 | 790 |
| N | Comp | 13.2 | 18.57 | 11.93 | 23.76 | 22.06 | 504 | 0.7 | 3.06 | 1.331 | 13.03 | 36.29 | 799 |
| O | Comp | 2.86 | 36.3 | 3.897 | 29.59 | 19.47 | 516 | 0.62 | 0.85 | 2.094 | 20.47 | 48.96 | 1,371 |
| Q | Comp | 12.4 | 8.08 | 3.724 | 5.68 | 7.18 | 1889 | 0.46 | 1.59 | 0.125 | 3.33 | 16.72 | 551 |
| R | Comp | 20 | 12.22 | 5.485 | 14.22 | 9.494 | 325 | 1.04 | 4.49 | 1.006 | 9.22 | 24.63 | 786 |
| T | Comp | 5.55 | 2.25 | 1.127 | 4.89 | 3.24 | 71 | 0.11 | 0.43 | 0.1 | 0.84 | 5.76 | 220 |

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 2-14.** Sequential Serial Soil Extracts Results, Inactive Pottery Factory

| Unit | Sampling Location | Untreated | | | | | | Treated | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 |
| U | 1 | 133.7 | 1,506 | 230.3 | 515.7 | 255.2 | 14,446 | 22.99 | 255.7 | 13.83 | 194.8 | 1,326 | 15,749 |
| U | 2 | 117.7 | 1,349 | 142.7 | 579.9 | 230.3 | 13,491 | 22.1 | 188.5 | 6.39 | 213.2 | 1,329 | 18,054 |
| U | 3 | 180.4 | 2,213 | 261.3 | 766.9 | 215.5 | 13,600 | 30.18 | 255.6 | 17.92 | 159.6 | 1,662 | 23,739 |
| U | 4 | 141.6 | 1,506 | 183.4 | 600.8 | 285 | 13,328 | 32.17 | 332.4 | 22.42 | 198.7 | 1,579 | 18,002 |
| U | 5 | 120.3 | 1,078 | 195.9 | 663.9 | 240.7 | 13,872 | 34.59 | 156.9 | 16.99 | 226.5 | 1,348 | 17,223 |
| U | 6 | n/s | n/s | n/s | n/s | n/s | n/s | 23.82 | 304.10 | 18.24 | 254.00 | 1,485 | 18,157 |
| U | 7 | n/s | n/s | n/s | n/s | n/s | n/s | 14.54 | 183.20 | 11.52 | 213.60 | 1,234 | 16,384 |
| U | 8 | n/s | n/s | n/s | n/s | n/s | n/s | 30.89 | 186.70 | 8.21 | 192.30 | 1,107 | 15,216 |
| U | 9 | n/s | n/s | n/s | n/s | n/s | n/s | 44.26 | 233.60 | 56.17 | 175.80 | 1,294 | 10,843 |

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 2-15.** 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 | 24.73 | 3.14 | 21.59 | 0.009 |
| Carbonate | 37.41 | 12.63 | 24.78 | 0.004[1] |
| Manganese Oxide | 8.31 | 3.5 | 4.81 | 0.003[1] |
| Iron Oxide | 29.84 | 22.96 | 6.88 | 0.0005[1] |
| Organic Matter | 20.39 | 59.86 | -39.47 | 0.03 |
| Residual | 922.8 | 1,545 | -622.2 | 0.02 |
| Inactive Pottery Factory | | | | |
| Exchangeable | 138.73 | 28.39 | 110.34 | 0.0002[1] |
| Carbonate | 1,530.45 | 232.99 | 1,297.46 | 0.001[1] |
| Manganese Oxide | 202.72 | 19.08 | 183.64 | 0.0002[1] |
| Iron Oxide | 625.44 | 203.18 | 422.26 | 0.0002[1] |
| Organic Matter | 385.6 | 1,373.9 | -988.3 | 0.00000001[1] |
| Residual | 13,751 | 17,040.78 | -3,289.78 | 0.009 |

Notes:
Hypothesis associated with significance level is $H_o$: mean untreated - mean treated = 0.
[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).

**Table 2-16.** Trailer Park Eh Analytical Results

| Experimental Unit | Sampling Location | Untreated Eh (mV) | Treated Eh (mV) |
|---|---|---|---|
| C | Composite | 620 | 590 |
| G | Composite | 690 | 580 |
| K | Composite | 620 | 530 |
| L | Composite | 570 | 770 |
| M | Composite | 490 | 1,100 |
| N | Composite | 600 | 700 |
| O | Composite | 570 | 800 |
| Q | Composite | 500 | 810 |
| R | Composite | 550 | 820 |
| T | Composite | 570 | 670 |

**Table 2-17.** Inactive Pottery Factory Eh Analytical Results

| Experimental Unit | Sampling Location | Untreated Eh (mV) | Treated Eh (mV) |
|---|---|---|---|
| U | 1 | 530 | 530 |
| U | 2 | 890 | 610 |
| U | 3 | 590 | 560 |
| U | 4 | 650 | 570 |
| U | 5 | 550 | 530 |
| U | 6 | n/s | 540 |
| U | 7 | n/s | 540 |
| U | 8 | n/s | 580 |
| U | 9 | n/s | 570 |

Note: n/s = not sampled.

| Table 2-18. Eh Summary Statistics | | |
|---|---|---|
| Statistic | Trailer Park Data (mV) | Inactive Pottery Factory Data (mV) |
| Untreated Mean (Standard deviation) | 578 (59) | 642 (146) |
| Treated Mean (Standard deviation) | 737 (165) | 559 (27) |
| Mean Difference (Untreated - Treated) | 159 | -83 |
| Significance level | 0.02 | 0.14 |

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.

stability. Overall, the results suggest that the application of Soil Rescue may either increase or not significantly affect the Eh of the treated soil; however, such changes in Eh did not appear to bring along increases in lead-oxide and manganese-oxide phases of lead, as evidenced by the reductions in the phases observed in the data from two lead speciation evaluations (discussed above). In summary, long-term chemical stability was not indicated for soils treated by Soil Rescue by the analytical results from oxidation-reduction (Eh) analysis.

## 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 Soil Rescue.

Table 2-19 presents the analytical results for pH in the soil from the trailer park. Table 2-20 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 2-21 shows the summary statistics associated with the analysis. Included in the table are the observed pH means 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 each site appears to be statistically significant. In addition, 4 of 10 pH values for treated soils from the trailer park are within the optimum range, and all pH values for treated soil from the inactive pottery factory are within the optimum range of 7.0 to 10.0. On the basis of those results, the application of Soil Rescue appears 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 Soil Rescue 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 Soil Rescue changed the mobility of the lead in the soil. Table 2-22 displays the CEC data from the trailer park, and Table 2-23 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 0.12 meq/g to the result for treated soil of 0.22 meq/g. CEC data for the inactive pottery factory also show an increase in the CEC from the result for untreated soil of 0.09 meq/g to the result for treated soil of 0.26 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 Soil Rescue 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.

**Table 2-19.** Trailer Park pH Analytical Results

| Experimental Unit | Sampling Location | Untreated | Treated |
|---|---|---|---|
| C | Composite | 5.9 | 6.8 |
| G | Composite | 6.2 | 7.5 |
| K | Composite | 5.9 | 6.5 |
| L | Composite | 6.5 | 6.7 |
| M | Composite | 6.9 | 6.7 |
| N | Composite | 6.3 | 7.8 |
| O | Composite | 7.8 | 6.8 |
| Q | Composite | 5.3 | 7.2 |
| R | Composite | 5.3 | 7.9 |
| T | Composite | 4.8 | 6.6 |

**Table 2-20.** Inactive Pottery Factory pH Analytical Results

| Experimental Unit | Sampling Location | Untreated | Treated |
|---|---|---|---|
| U | 1 | 6.9 | 8.2 |
| U | 2 | 7.5 | 8.0 |
| U | 3 | 7.4 | 7.8 |
| U | 4 | 7.5 | 7.7 |
| U | 5 | 7.4 | 7.9 |
| U | 6 | n/s | 8.2 |
| U | 7 | n/s | 7.8 |
| U | 8 | n/s | 7.9 |
| U | 9 | n/s | 8.1 |

Note: n/s = Not sampled

**Table 2-21.** pH Summary Statistics

| Statistic | Trailer Park Data | Inactive Pottery Factory Data |
|---|---|---|
| Untreated Mean[1] | 5.52 | 7.27 |
| Treated Mean[1] | 6.85 | 7.92 |
| Mean Difference (Untreated - Treated) | 1.33 | 0.65 |
| Significance level | 0.041 | 0.049 |

Notes:
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.

[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 2-19 and 2-20.

**Table 2-22.** 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 | 0.0022 | 0.0022 | 0.0987 | 0.0129 | 0.0046 | 0.0000 | 0.0003 | 0.1190 |
| Treated | 0.0023 | 0.0001 | 0.0544 | 0.0108 | 0.1475 | 0.0000 | 0.0048 | 0.2199 |

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

| Table 2-23. 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 | 0.0038 | 0.0001 | 0.0759 | 0.0083 | 0.0010 | 0.0000 | 0.0000 | 0.0893 |
| Treated | 0.0141 | 0.0001 | 0.0406 | 0.0150 | 0.1880 | 0.0000 | 0.0047 | 0.2626 |
| Note: meq/g = milliequivalents per gram = weight of element in soil (mg) x ÷ (atomic weight [g] ÷ valence) per gram of soil. | | | | | | | | |

## Acid Neutralization Capacity

One soil sample was collected before and another after the application of Soil Rescue 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 0.0846 meq/g to the result for treated soils of 0.1214 meq/g. The data on acid neutralization capacity data for the inactive pottery factory indicate that there was a decrease from the data on the result for untreated soil of 0.6329 meq/g to the result for treated soil of 0.5013 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 Soil Rescue. 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 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.

Both procedures were used to determine 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. It should be noted that 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 2-24 lists the concentrations of lead determined by nitric acid digestion of untreated and treated soil from the trailer park, and Table 2-25 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 2-26 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 increased from 1,802.8 mg/kg to 2,168.9 mg/kg, while the mean concentration of lead in soil from the inactive pottery factory decreased from 34,740 mg/kg to 31,422.2 mg/kg. However, the corresponding t-scores indicate that neither of the observed

**Table 2-24.** Lead Analytical Results for Nitric Acid Digestion for Soil from the Trailer Park

| Experimental Unit | Sampling Location | Untreated (mg/kg) | Treated (mg/kg) |
|---|---|---|---|
| C | Composite | 345 | 409 |
| G | Composite | 4,330 | 4,900 |
| K | Composite | 2,170 | 1,580 |
| L | Composite | 4,440 | 9,260 |
| M | Composite | 2,200 | 1,480 |
| N | Composite | 1,320 | 1,090 |
| O | Composite | 1,550 | 1,510 |
| Q | Composite | 496 | 478 |
| R | Composite | 907 | 766 |
| T | Composite | 270 | 216 |

**Table 2-25.** Lead Analytical Results for Nitric Acid Digestion for Soil from the Inactive Pottery Factory

| Experimental Unit | Sampling Location | Untreated (mg/kg) | Treated (mg/kg) |
|---|---|---|---|
| U | 1 | 40,600 | 30,900 |
| U | 2 | 28,200 | 22,400 |
| U | 3 | 41,100 | 42,700 |
| U | 4 | 36,300 | 29,500 |
| U | 5 | 27,500 | 26,800 |
| U | 6 | n/s | 43,300 |
| U | 7 | n/s | 34,200 |
| U | 8 | n/s | 22,300 |
| U | 9 | n/s | 30,700 |

Note: n/s = not sampled.

**Table 2-26.** Summary Statistics for Nitric Acid Digestion

| Statistic | Trailer Park Data (mg/kg) | Inactive Pottery Factory Data (mg/kg) |
|---|---|---|
| Untreated mean (Standard deviation) | 1,802.8 (1,524) | 34,740.0 (6,565) |
| Treated mean (Standard deviation) | 2,168.9 (2,826) | 31,422.2 (7,636) |
| Mean Difference (Untreated - Treated) | -366.1 | 3,317.80 |
| Level of significance | 0.2 | 0.2 |

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.

differences is statistically significant. Therefore, the statistical analysis of the data suggests that, for both sites, there are no significant differences in mean concentrations of total lead between untreated and treated soils using the nitric acid digestion method for total lead.

Table 2-27 presents the concentrations of lead determined by hydrofluoric acid digestion of untreated and treated soil from the trailer park, and Table 2-28 presents the concentrations of lead determined by hydrofluoric acid digestion of untreated and treated soils from for 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 2-29 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 increased

**Table 2-27.** Lead Analytical Results Using Hydrofluoric Acid Digestion for the Trailer Park

| Experimental Unit | Sampling Location | Untreated (mg/kg) | Treated (mg/kg) |
|---|---|---|---|
| C | Composite | 413 | 398 |
| G | Composite | 4,080 | 13,000 |
| K | Composite | 2,010 | 2,660 |
| L | Composite | 6,140 | 6,420 |
| M | Composite | 838 | 2,740 |
| N | Composite | 1,060 | 1,150 |
| O | Composite | 808 | 1,710 |
| Q | Composite | 507 | 450 |
| R | Composite | 825 | 772 |
| T | Composite | 301 | 275 |

**Table 2-28.** Lead Analytical Results Using Hydrofluoric Acid Digestion for the Inactive Pottery Factory

| Experimental Unit | Sampling Location | Untreated (mg/kg) | Treated (mg/kg) |
|---|---|---|---|
| U | 1 | 42,900 | 47,800 |
| U | 2 | 49,100 | 39,400 |
| U | 3 | 55,700 | 42,300 |
| U | 4 | 47,000 | 33,700 |
| U | 5 | 47,800 | 27,200 |
| U | 6 | n/s | 40,900 |
| U | 7 | n/s | 33,200 |
| U | 8 | n/s | 31,800 |
| U | 9 | n/s | 35,800 |

Note: n/s = not sampled.

**Table 2-29.** Summary Statistics for Hydrofluoric Acid Digestion

| Statistic | Trailer Park Data (mg/kg) | Inactive Pottery Factory Data (mg/kg) |
|---|---|---|
| Untreated Mean (Standard deviation) | 1,698.2 (1,921) | 48,500 (4,645) |
| Treated Mean (Standard deviation) | 2,957.5 (3,981) | 36,900 (6,279) |
| Mean Difference (Untreated - Treated) | -1,259.30 | 11,600 |
| Significance level | 0.092 | 0.002 |

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.

from 1,698.2 mg/kg to 2957.5 mg/kg, while the mean concentration of lead in soil from the pottery factory decreased from 48,500 mg/kg to 36,900 mg/kg. The change in the mean concentrations of lead is not statistically significant at the trailer park, according to the t-score value, which is the expected outcome of the analysis. However, the decrease in total concentrations of lead at the inactive pottery factory is considered significant. Therefore, the statistical analysis of those data suggests that there was no difference in concentrations of lead between treated and untreated soils for soils from the trailer park and a significant decrease in mean concentration of lead in treated soil from the pottery factory, as determined by the 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 inactive pottery factory 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 Soil Rescue).

## 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 Soil Rescue decreased the solubility of the lead in the soil. The criterion selected for determining whether the application of Soil Rescue had an effect on the soil was a concentration of SPLP lead in treated soil of less than 5.0 mg/L.

Table 2-30 lists the concentrations of SPLP lead in untreated and treated soil from the trailer park. The

| Table 2-30. SPLP Lead Analytical Results for Soil from the Trailer Park | | | |
|---|---|---|---|
| Experimental Unit | Sampling Location | Untreated (mg/L) | Treated (mg/L) |
| C | Composite | <0.50 | <0.50 |
| G | Composite | <0.50 | 3.1 |
| K | Composite | <0.50 | <0.50 |
| L | Composite | <0.50 | <0.50 |
| M | Composite | <0.50 | 1.2 |
| N | Composite | <0.50 | <0.50 |
| O | Composite | <0.50 | 0.67 |
| Q | Composite | <0.50 | <0.50 |
| R' | Composite | <0.50 | <0.50 |
| T | Composite | <0.50 | <0.50 |

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, 3 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.

A parametric statistical analysis of the concentrations of SPLP lead in treated soil cannot be performed because of the excessive number of nondetects. However, the following nonparametric argument can be made to support a conclusion that SPLP 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 at less than 5.0 mg/L could be no more than $(0.5)10 = 0.00098$. 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. The statistical analysis of untreated and treated soil from the trailer park did not indicate a statistically significant change in concentrations of SPLP lead.

Table 2-31 lists the concentrations of SPLP lead 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. All the concentrations of SPLP lead in treated soil from the inactive pottery factory exceed the regulatory limit of 5 mg/L. Table 2-32 shows the pertinent summary statistics for SPLP data on treated soil from the inactive pottery factory. The statistics include the estimated mean, standard deviation, and 95 percent upper confidence limit (UCL) for the SPLP data on treated soil, assuming that the data are distributed normally. The estimated mean concentration of SPLP lead in soil from the inactive pottery factory was 8.78 mg/L, with a 95 percent UCL of 9.76 mg/L. Because the UCL estimate is significantly higher than 5.0 mg/L, the concentrations of SPLP lead in the treated soil indicate that the treated soil may leach small amounts of lead. In fact, the mean concentrations of SPLP lead in the treated soils from the inactive pottery factory appear to be significantly higher than the mean concentrations of TCLP lead (3.3 mg/L; see Table 2-6) in those same treated soils. These results are unexpected, since the TCLP generally results in higher concentrations of leachable lead than the SPLP. Those differences cannot be explained without further testing. However, the different acids used for the TCLP and the SPLP (acetic for CLP; sulfuric and nitric for the SPLP) may have contributed to the differences. Further, the results of the MEP tests (in which acetic acid is used initially, followed by sulfuric and nitric acids) that were conducted on soils from the inactive pottery factory and shown in Table 2-11 indicate that the concentrations of lead leached from both untreated and treated soils by sulfuric and nitric acids are much higher than those shown in Table 2-31.

| Summary of Results for Objective S1 | | | |
|---|---|---|---|
| | | Interpretation | |
| Procedure | Results | Trailer Park | Pottery Factory |
| MEP | All results met the acceptance criteria for SI (see Table 2-4). | Soil Rescue 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. | Inconclusive: Lead in phosphates and glass appears to increase, and lead in oxide phases appear to decrease after addition of Soil Rescue; however, lead in organic matter appears to increase. | This procedure was not conducted on soils from this location. |
| Lead speciation by sequential extractions | Results for three of six phases of lead at one site, and four of six at the other site met the acceptance criteria for S1. One phase did not meet the criteria, and the four other phases did not appear to be affected by the treatment. | Inconclusive: Soil Rescue exhibits some long-term stability, as indicated by the results of this procedure. Lead in carbonate and oxide phases was reduced, and exchangeable lead may have been reduced. However, organic lead may have been increased, and residual lead appeared to be unchanged. | Soil Rescue did not increase the long-term stability, as indicated by this procedure. Exchangeable lead and lead in carbonate and oxide phases were reduced, and residual lead may have been increased. However, organic lead increased. |
| Eh | The criterion for S1 was not met for either site. | Soil Rescue did not increase long-term stability, as indicated by the results of this procedure. | Soil Rescue did not increase long-term stability, as indicated by the results of this procedure. |
| pH | All results met the acceptance criteria for S1 (see Table 2-4). | Soil Rescue increased 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). | Soil Rescue increased 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. | Soil Rescue increases long-term stability, as indicated by the results of this procedure. | Soil Rescue did not exhibit long-term stability, based on 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 SI (see Table 2-4). | Soil Rescue does not increase long-term stability, as indicated by the results of this procedure. | |
| SPLP lead | The acceptance criterion for S1 was met at one site but was not met at the other site. | Soil Rescue increases long-term stability, as indicated by the results of this procedure. However, SPLP lead concentrations were significantly higher in the treated soils. | Soil Rescue did not exhibit long-term stability, based on the results of this procedure. |
| Total phosphate | None of the results met the acceptance criteria for S1 (see Table 2-4). | Soil Rescue does 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 meaninful 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). | Soil Rescue does not increase long-term stability, as indicated by the results of this procedure. | |
| Note: [1] These tests are considered to be qualitative, because only one sample at each site was tested by this procedure. | | | |

**Table 2-31.** SPLP Lead Analytical Results for Soil from the Inactive Pottery Factory

| Experimental Unit | Sampling Location | Untreated (mg/L) | Treated (mg/L) |
|---|---|---|---|
| U | 1 | <0.50 | 8.8 |
| U | 2 | <0.50 | 7.6 |
| U | 3 | <0.50 | 10.7 |
| U | 4 | <0.50 | 10.3 |
| U | 5 | <0.50 | 10.2 |
| U | 6 | n/s | 8.9 |
| U | 7 | n/s | 7.0 |
| U | 8 | n/s | 6.5 |
| U | 9 | n/s | 9.1 |

Note: n/s = not sampled.

In summary, on the basis of the criterion of 5 mg/L for SPLP lead, the long-term stability of the treated soil appears to have been reduced at the inactive pottery factory by the application of Soil Rescue. The results for treated soil from the trailer park are consistent with long-term stability.

## Phosphates

Soil Rescue 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 Soil Rescue 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 comparisons of the concentrations of phosphate that leach from untreated and treated soil when the SPLP test (SW-846 Method 1312) is applied (analyzing the SPLP extract for total phosphates by SW-846 Method 9056).

Table 2-33 lists the total concentrations of phosphate for soil from the trailer park, and Table 2-34 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 Soil Rescue.

Table 2-35 lists the concentrations of SPLP phosphates for untreated and treated soils from the trailer park, and

**Table 2-32.** SPLP Lead Summary Statistics for Soil from the Inactive Pottery Factory

| Statistic | Data |
|---|---|
| Mean (mg/L) | 8.78 |
| Standard Deviation | 1.49 |
| 95% UCL | 9.76 |

Table 2-36 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 Soil Rescue.

Table 2-37 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 total phosphates were 701.4 mg/kg for the trailer park and 2,145 mg/kg for the inactive pottery factory. The estimated mean concentrations of SPLP phosphates were 49.3 mg/L and 107.7 mg/L for the trailer park and the inactive pottery factory, respectively. On the basis of the data obtained by conduct of analytical procedures, it appears that phosphates from the application of Soil Rescue could leach from the soil, a circumstance that could affect nearby surface water.

The results of the conduct of most of the procedures indicate that Soil Rescue appears to increase long-term stability. However, the results of some of the procedures suggest that Soil Rescue does not increase long-term stability. Long-term stability of soil was indicated for soils treated by Soil Rescue at both test locations, as shown by the analytical results of the MEP, pH, and CEC 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 following tests: lead speciation by sequential extraction, Eh, acid neutralization capacity, and SPLP lead. The analytical results or testing by the lead speciation by SEM (conducted only on soils from the trailer park) were mixed in that some soluble species of lead were reduced, while the organic matter phase of lead was increased. Lead bound to organics can be released if the organic phase is biologically degraded by microbes in the soil. For both locations, long-term stability of soil was not indicated for soils treated by Soil Rescue by the results of separate analyses for total lead by nitric and hydrofluoric acids (higher concentrations of total lead using the hydrofluoric acid method would have indicated long-term

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

| Experimental Unit | Sampling Location | Untreated (mg/kg) | Treated (mg/kg) |
|---|---|---|---|
| C | Composite | <13.2 | 235 |
| G | Composite | <12.7 | 1,250 |
| K | Composite | <12.4 | 580 |
| L | Composite | <12.1 | 674 |
| M | Composite | <11.5 | 663 |
| N | Composite | <12.1 | 1,600 |
| O | Composite | <12.2 | 680 |
| Q | Composite | <11.5 | 781 |
| R | Composite | <11.2 | 192 |

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

| Experimental Unit | Sampling Location | Untreated (mg/kg) | Treated (mg/kg) |
|---|---|---|---|
| U | 1 | <12.7 | 2,180 |
| U | 2 | <13.4 | 2,270 |
| U | 3 | <13.0 | 1,950 |
| U | 4 | <13.7 | 1,620 |
| U | 5 | <13.5 | 3,530 |
| U | 6 | n/s | 1,730 |
| U | 7 | n/s | 2,340 |
| U | 8 | n/s | 1,550 |
| U | 9 | n/s | 2,110 |
| Note: n/s = Not sampled | | | |

**Table 2-35.** SPLP Phosphates Analytical Results for Soil from the Trailer Park

| Experimental Unit | Sampling Location | Untreated (mg/L) | Treated (mg/L) |
|---|---|---|---|
| C | Composite | <1.0 | 30.2 |
| G | Composite | <1.0 | 75.5 |
| K | Composite | <1.0 | 53.2 |
| L | Composite | <1.0 | 41.3 |
| M | Composite | <1.0 | 40.2 |
| N | Composite | <1.0 | 93.7 |
| O | Composite | <1.0 | 44.4 |
| Q | Composite | <1.0 | 52.8 |
| R | Composite | <1.0 | 27.2 |
| T | Composite | <1.0 | 34.2 |

**Table 2-36.** SPLP Phosphates Analytical Results for Soil from the Inactive Pottery Factory

| Experimental Unit | Sampling Location | Untreated (mg/L) | Treated (mg/L) |
|---|---|---|---|
| U | 1 | <1.0 | 96.0 |
| U | 2 | <1.0 | 101 |
| U | 3 | <1.0 | 89.2 |
| U | 4 | <1.0 | 62.0 |
| U | 5 | <1.0 | 126 |
| U | 6 | n/s | 66.4 |
| U | 7 | n/s | 107 |
| U | 8 | n/s | 72.6 |
| U | 9 | n/s | 249 |
| Note: n/s = Not sampled | | | |

| Table 2-37. Phosphate Summary Statistics | | | |
|---|---|---|---|
| Location | Data | Mean | 95% Confidence Interval |
| Trailer Park | Total phosphates (mg/kg) | 701.4 | (430—973) |
| | SPLP phosphates (mg/L) | 49.3 | ( 36–62) |
| Pottery Factory | Total phosphates (mg/kg) | 2,145 | ( 1,757—2,532) |
| | SPLP phosphates (mg/L) | 107.7 | ( 71—145) |

stability), total phosphates (significant increases in total phosphates create a higher potential for environmentally damaging releases of phosphates to surface waters), and leachable phosphates as indicated by the SPLP.

### 2.4.4 Evaluation of S2

*Demonstrate that the application of Soil Rescue 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 $\mu m/m^3$ of air, averaged over a period of three consecutive months. Table 2-38 lists the exposures calculated for the worker during the demonstration.

The only sample result in the detectable range, 24 $mg/m^3$, 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 135 hours. The application of Soil Rescue 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 Soil Rescue.*

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.

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 Soil Rescue. 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.

| Table 2-38. 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 $\mu$ g/m$^3$ |
| Area Sample East | 9/22/98 | 5 | 10 | 50.0 | <4.0$\mu$ g/m$^3$ |
| Area Sample Northeast | 9/22/98 | 5 | 10 | 50.0 | <4.0 $\mu$ g/m$^3$ |
| Area Sample North | 9/22/98 | 5 | 10 | 50.0 | <4.0 $\mu$ g/m$^3$ |
| Area Sample Southwest | 9/25/98 | 5 | 10 | 50.0 | <4.0 $\mu$ g/m$^3$ |
| Area Sample East | 9/25/98 | 5 | 10 | 50.0 | 24 $\mu$ g/m$^3$ |
| Area Sample Northeast | 9/25/98 | 5 | 10 | 50.0 | <4.0 $\mu$ g/m$^3$ |
| Area Sample North | 9/25/98 | 5 | 10 | 50.0 | <4.0 $\mu$ g/m$^3$ |
| Notes: $\mu$ g/m$^3$ = Micrograms per cubic meter of air | | | | | |

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 Soil Rescue 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 Soil Rescue.*

On the basis of information obtained through the SITE evaluation from Star Organics and from other sources, an economic analysis examined 12 cost categories for a scenario in which Soil Rescue 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 Soil Rescue 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 sampling of treated soil for analysis for bioavailable lead. Analytical results for the equipment and field blanks for untreated soils and subsequent long-term monitoring blanks did not indicate cross-contamination as a result of sample collection or shipping procedures. Therefore, the deviation should not affect overall data quality. All 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 the TCLP lead data were considered usable. Therefore, the critical parameters of bioavailable and TCLP lead data are considered 100 percent complete.

### 2.5.2 Comparability and Project-Required Detection Limits

On the basis of consistent implementation of a reference method, data on critical parameters (bioavailable lead and TCLP lead) for samples of untreated and treated soil are considered to be comparable. As specified by the QAPP, the University of Colorado used the SBRC's, SIVM to analyze soil samples for bioavailable lead, and Quanterra used SW-846 Method 1311 (EPA 1996) to analyze soil samples for concentrations of TCLP lead. 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 the assessments of precision and accuracy 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. Appendix B presents the QC data for the critical and noncritical parameters.

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 samples of untreated soil. Therefore, the deviation should have no effect on 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 the RPDs for the MS/MSD and LCS/LCSD samples were less than 20 percent and therefore were acceptable.

### 2.5.4 Representativeness

The University of Colorado analyzed method blank samples for bioavailable lead to confirm the representativeness of the data on bioavailable lead by determining whether any lead might have been introduced during preparation and analysis of the samples. The levels of lead in the method blank samples did not exceed the criteria set forth in the QAPP for method blanks, which is 25 µg/L. Therefore, the method blank analyses do not indicate that laboratory contamination introduced detectable concentrations of the critical parameter bioavailable lead into 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, as indicated by the available QC data.

Quanterra analyzed method blank samples for TCLP lead to confirm the representativeness of the TCLP lead data by determining whether any lead might have been introduced during sample preparation and analysis of the samples. Quanterra did not detect any TCLP lead in any of the method blanks at levels higher than 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 into any of the samples, and the reported concentrations of the parameter TCLP lead appear to be representative of actual concentrations in the soil samples, as indicated by the available QC data.

Tetra Tech prepared equipment blank samples and field blank samples to determine whether any lead might have been introduced by sample collection, handling, and

packaging procedures. Section 2.5.1 of the TER summarizes the blank sample preparation techniques. No lead was detected in any of the blank samples at levels higher than the PRDL of 100 µg/L.

The University of Colorado analyzed the equipment blank and field blank samples for bioavailable lead to confirm the representativeness of the data on bioavailable lead by determining whether any bioavailable lead might have been introduced during sample collection, handling, and packaging. The University of Colorado did not detect any bioavailable lead in any of the equipment and field blanks at levels higher than the PRDL of 100 µg/L. Therefore, the results of analysis of the equipment and field blanks do not indicate that sample collection, handling and packaging procedures introduced detectable concentrations of the critical parameter bioavailable lead into 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 whether any lead might have been introduced during sample collection, handling and packaging. Quanterra did not detect any TCLP lead in any of the equipment and field blanks at levels higher than the PRDL of 0.50 mg/L. Therefore, the analysis of equipment and field blanks do not indicate that sample collection, handling and packaging procedures introduced detectable concentrations of the critical parameter TCLP lead into any of the samples.

# Section 3
# Technology Applications Analysis

This section describes the Soil Rescue 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

Soil Rescue is added to soils or wastes contaminated with toxic metals. Soil Rescue is an alkaline solvent made by a proprietary method that involves the extraction of organic acids and alcohols and the formation of phosphoryl esters in a batch process. Raw materials for the proprietary extractant include a medley of compost sources, which are extracted in a ratio that Star Organics has tested and found to provide the widest spectrum, and highest concentration, of desirable complexing components. Star Organics claims that Soil Rescue converts the metal contaminant from its leachable form to an insoluble, stable, nonhazardous, organometallic complex. Soil Rescue is a mixture of weak organic acids and phosphoryl esters that act as metal-complexing agents. In the complexation reaction, the metal ions, the organic acids and esters, and the soil substrate form coordinate covalent bonds. Star Organics claims that the formation of metal complexes by Soil Rescue reduces the waste stream's TCLP test results to less than the regulatory levels, thereby reducing the risks posed to human health and the environment (Star Organics 2000). The process generates no secondary wastes, and minimal handling, transportation, and disposal costs are incurred.

## 3.2 APPLICABLE WASTES

Star Organics claims that Soil Rescue can treat heavy metals in soils, sludges, mine tailings, and process residues and other solid waste. Star Organics states that Soil Rescue can stabilize the following heavy metals: barium, cadmium, chromium, copper, lead, mercury, selenium, and zinc (Star Organics 2000). Soil Rescue can be applied *in situ* at sites at which soils are moderately permeable. A second treatment may be necessary for more difficult metals (selenium), depending on the amount of contamination and the presence of competing metals in the soil (toxic and nontoxic).

## 3.3 METHOD OF APPLICATION

Farm or construction equipment can be used to apply Soil Rescue at large sites, and simple gardening or small construction equipment can be used at small treatment areas. For example, Soil Rescue was applied to the surface of the experimental units and injected to a depth of two feet with a pressurized sprayer.

Star Organics selects a site-specific concentration of Soil Rescue by determining the density, volume, weight, and amount of contamination present in the soil through bench-scale studies of soil samples. An evaluation of the soil chemistry at the site must be performed to determine the concentration of the contaminant throughout the site and the concentration of other metals that may be present at the site. Such site conditions 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 space to store the equipment necessary to apply the technology. No utilities are required for the application of the technology. Potable water is required for decontamination of equipment and personnel.

## 3.4 MATERIAL HANDLING REQUIREMENTS

Soil Rescue is nonhazardous and requires no special handling procedures. All field equipment and personal protection equipment (PPE) must be decontaminated after the soil has been treated. For the CRPAC demonstration, decontamination was accomplished with soap, water, and Alconox, followed by a rinse with deionized water. While Soil Rescue is expected to generate little residual waste, any soil on the equipment, any fluids used in the decontamination process, and any disposable PPE must be treated as a potentially hazardous waste. The waste should be characterized for proper disposal.

## 3.5 LIMITATIONS OF THE TECHNOLOGY

In soils in which concentrations of other metals are high, it may be necessary to reapply Soil Rescue until the leachable concentration of the heavy metal is reduced to a level that is lower than the applicable cleanup standard. In addition, Soil Rescue appears to increase the potential that phosphates will leach from the treated soils and affect surface water.

## 3.6 REGULATORY REQUIREMENTS

This section discusses environmental regulations that may pertain to the application of Soil Rescue. 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 Soil Rescue, 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 Soil Rescue 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 Soil Rescue 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 Soil Rescue 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 works 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 Star Organics 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 Soil Rescue. In general, latex or nitrile gloves, Tyvek coveralls, boot covers, and goggles are recommended for applying Soil Rescue 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

Soil Rescue is available from Star Organics, Dallas, Texas (see Section 1.4 for the address and other contact information). Soil Rescue is nonhazardous and was

transported to the CRPAC demonstration site by a medium-duty truck. No special permit or licensing was required for transport of the material, and there are no restrictions on the transportation of the material. All equipment necessary for the application of Soil Rescue is readily available from local rental companies and need not be obtained from Star Organics.

## 3.8 COMMUNITY ACCEPTANCE BY THE STATE AND THE COMMUNITY

State and community acceptance of Soil Rescue 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 Soil Rescue.

This economic analysis presents two cost estimates for the application of Soil Rescue (not including profit) to commercially remediate soil contaminated with lead. The estimates are based on assumptions and costs provided by Star Organics; 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 Soil Rescue. 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 Soil Rescue. 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.

# Section 4
# Economic Analysis

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 Soil Rescue 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 Soil Rescue 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 Soil Rescue 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 Star Organics and observations made during the SITE demonstration. For both cases, costs were based on information provided by Star Organics, 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.

For both cases, assumptions made about site- and waste-related factors 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.

**Table 4-1.** Cost Distribution for Soil Rescue

| Cost Categories | Case 1 (5 yd³) | | | Case 2 (807 yd³) | | |
|---|---|---|---|---|---|---|
| | Costs | Cost/yd³ | % Costs | Costs | Cost/yd³ | % Costs |
| (1) Site Preparation | | | | | | |
| Rental Equipment | $30 | | | $115 | | |
| Labor and Per Diem | $1,350 | | | $1,350 | | |
| Total Site Preparation Costs | $1,400 | $280 | $10.94 | $1,500 | $1.86 | $4.62 |
| (2) Permitting and Regulatory | — | — | — | — | — | — |
| (3) Mobilization | | | | | | |
| Mileage | $300 | | | $300 | | |
| Labor and Per Diem | $2,700 | | | $2,700 | | |
| Total Mobilization Costs | $3,000 | $600 | $23.44 | $3,000 | $3.72 | $9.23 |
| (4) Equipment | | | | | | |
| Rental Equipment | $100 | | | $700 | | |
| Purchased Equipment | $200 | | | — | | |
| Total Equipment Costs | $300 | $60 | $2.34 | $700 | $0.87 | $2.15 |
| (5) Labor | | | | | | |
| Labor | $4,700 | | | $6,200 | | |
| Per Diem | $800 | | | $800 | | |
| Total Labor Costs | $5,500 | $1,100 | $42.97 | $7,000 | $8.67 | $21.54 |
| (6) Supplies and Materials | | | | | | |
| Soil Rescue | $100 | | | $12,100 | | |
| Sampling Supplies | $200 | | | $400 | | |
| PPE and Decontamination Supplies | $500 | | | $800 | | |
| Misc. Field Supplies | $200 | | | $300 | | |
| Total Supplies and Materials Costs | $1,000 | $200 | $7.81 | $13,600 | $16.85 | $41.85 |
| (7) Utilities | — | — | — | — | — | — |
| (8) Effluent Treatment & Disposal | — | — | — | — | — | — |
| (9) Residual Waste Shipping | — | — | — | $1,000 | $1.24 | $3.08 |
| (10) Analytical Services | $1,600 | $320 | $12.50 | $4,200 | $5.20 | $12.92 |
| (11) Equipment Maintenance | — | — | — | — | — | — |
| (12) Site Demobilization | | | | | | |
| Mileage | $300 | | | $300 | | |
| Labor and Per Diem | $2,700 | | | $2,700 | | |
| Total Site Demobilization | $3,000 | $600 | $23.44 | $3,000 | $3.72 | $9.23 |
| Total Costs | $15,880 | $3,160 | $100 | $32,500 | $40.27 | $100 |

Note: 1998 dollars.

- 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 the some clearing and grubbing will be necessary to prepare the site for the application of Soil Rescue.
- 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 Soil Rescue 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 include:

- Star Organics provides on-site personnel during all phases of the treatment.
- A 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 Star Organics 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 Soil Rescue.
- Maintenance costs are included in the equipment rental cost.
- Soil Rescue is transported from the office of Star Organics in Dallas, Texas, 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 Soil Rescue: (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 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 such costs are site-specific, they are not included in the costs of site preparation presented in the estimates.

For this cost analysis, only site preparation costs specific to the technology are included. Those costs are limited to preparation of the site for the application of Soil Rescue by removal of grass at the site with a sod cutter or by tilling it into the soil. The treatment depth for both cases is 6 inches. Table 4-2 presents site preparation costs for both cases.

**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.

For Case 1, it is assumed that sod covering the site will be removed with sod cutters and stored until it can be replaced after treatment. Site preparation costs for Case 1 include rental costs for sod removal and tilling equipment, labor, and per diem. Assuming that 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 rental of equipment to remove sod, labor, and per diem. Since the sod would be removed with large, production-sized equipment, it is assumed that the one-acre site can be prepared in 8 hours and that all grass covering the site will be tilled into the soil. Equipment for the one-acre site would include a medium-duty tractor with a plow. On the basis of several vendor quotes, the weekly rental rate for the equipment is estimated to be $800, making daily cost for the equipment approximately $115. Assuming three that workers earning an estimated labor rate of $47.40 per hour will perform the work, labor costs associated with Case 2 will be $1,100. The total per diem for the three workers is $240. The total site preparation costs for Case 2 are an estimated $1,500.

### 4.3.2 Permitting and Regulatory Costs

Permitting and regulatory costs generally are the obligation of the responsible party (or site owner), not that of the vendor. Such costs may include the costs of permits, 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 Soil Rescue under a soil remediation program, permitting and regulatory costs will vary according to whether remediation is performed at a Superfund or a RCRA corrective action site. Remedial actions at Superfund site must be consistent with ARARs of environmental laws, ordinances, regulations, and statutes, including federal, state, and local standards and criteria. Remediation at RCRA corrective action sites requires certain monitoring and recordkeeping that can increase the basic cost of regulatory compliance.

No permitting costs are included in this analysis; however, depending on the site, such costs may be a significant factor because permitting can be expensive and time-consuming. The costs are not included in the analysis because no regulatory permits were required for Case 1. Permits may be needed for air emissions if site preparation activities produce significant quantities of dust. However, air emissions can be controlled by wetting the soil to be treated during tilling. Such costs are expected to be negligible and are not included in the 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 waste.

### 4.3.3 Mobilization Costs

Table 4-3 presents the mobilization costs for both cases. Mobilization consists 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 Star Organics in Dallas, Texas, to the CRPAC. The distance between Dallas, Texas, and the CRPAC site in Crooksville/Roseville, Ohio, is approximately 1,100 miles. Star Organics mobilized two field personnel and one truck for the SITE demonstration. It is assumed that for Case 2, two personnel and one truck also will be mobilized. Assuming the standard government mileage reimbursement rate of 31 cents per mile, mileage costs from Dallas, Texas, to the CRPAC were approximately $300. The drive from Dallas, Texas, to the CRPAC site requires approximately 20 hours of driving time. Labor costs for mobilizing two personnel (for a total of 40 hours of labor) earning an estimated labor rate of $54 per hour are approximately $2,200. 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 are $480. The total mobilization cost for both cases is approximately $3,000. Mobilization of personnel and

**Table 4-3.** Mobilization Costs

| Cost Category | Case 1 | Case 2 |
|---|---|---|
| Mileage | $ 300 | $ 300 |
| Labor (40 hours total) ($54/hr x 20 hrs x 2 workers) | $ 2,200 | $ 2,200 |
| Per diem ($80/worker/day x 3 days x 2 workers) | $ 480 | $ 480 |
| Total Mobilization Costs | $ 3,000 | $ 3,000 |

Note: 1998 dollars.

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. Such options should be explored to minimize the cost of mobilization.

### 4.3.4 Equipment Costs

Table 4-4 presents equipment costs for both cases. Rental equipment used during the SITE demonstration consisted of a polypropylene storage tank, a pump, a generator, and a tiller. The equipment was used over a two-day period. The daily rental cost for the tiller is approximately $23 (when rented for one week). Therefore, the cost for the tiller over the two-day period was $46. The total cost for the rest of the rental equipment for Case 1 was approximately $400 per week, bringing the cost for this equipment over the two-day period to approximately $57. Therefore the total cost for rental equipment was approximately $100. Purchased equipment used for Case 1 consisted of a fertilizer sprayer and a pressure sprayer for decontamination. The total cost of purchased equipment for Case 1 was approximately $200. Therefore, total cost for equipment for Case 1 is approximately $300.

It is assumed that for Case 2 the application of Soil Rescue requires larger production-sized equipment. To minimize costs, the equipment necessary for Case 2 should be rented. Equipment for Case 2 is assumed to be a tractor with both a plow and a fertilizer spreader and a pressure washer for decontamination. For Case 2, it is assumed that treatment will require three days. The daily rental cost for the tractor and plow is approximately $115, bringing the cost for the equipment to $345 for the three-day period. The combined one-week rental rates for the pressure washer and the fertilizer sprayer is estimated to be $800, bringing the daily rental cost for the equipment to $115. For the three-day time period assumed for Case 2, the cost for the pressure sprayer and the fertilizer sprayer is $345. Therefore, the total cost of equipment for Case 2 is estimated at approximately $700.

**Table 4-4.** Equipment Costs

| Cost Category | Case 1 | Case 2 |
|---|---|---|
| Rental equipment | $ 100 | $ 700 |
| Purchased equipment | $ 200 | — |
| Total Capital Equipment Cost | $ 300 | $ 700 |

Note: 1998 dollars.

### 4.3.5 Labor Costs

Once the site has been prepared and the technology has been mobilized, labor requirements for applying Soil Rescue are minimal. Table 4-5 summarizes labor costs. For both cases, it is assumed that two field personnel will be required for sampling activities, at an estimated labor rate of $47.40 per hour. It also is assumed that two workers will be required to perform the treatment activities, each at a labor rate of $54 per hour. All workers will 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. Sampling of untreated and treated soil, each activity lasting 1 day, was performed by Tetra Tech and required a total of 44 hours of labor. Labor costs associated with the sampling activities for Case 1 were approximately $2,100. The treatment performed by Star Organics required 24 hours and lasted three days, for a total of 48 hours of labor. The total cost of labor for the treatment activities associated with Case 1 was approximately $2,600. The total per diem for two workers over the five-day period was $800. Therefore, the total costs of labor associated with Case 1, including per diem, was $5,500.

For Case 2, sampling activities 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 require approximately 80 hours of labor over a five-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 five-day period is $800. Therefore, the total cost of labor associated with Case 2, including per diem, is estimated to be $8,120. Labor costs associated with

**Table 4-5.** Labor Costs

| Cost Category | Case 1 | Case 2 |
|---|---|---|
| Sampling Labor ($47.40/hr x hours) | $2,100 (44 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) | $800 | $800 |
| Total Labor Costs | $5,500 | $8,120 |

Note: 1998 dollars.

laboratory analysis 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 Soil Rescue include Soil Rescue, sampling supplies, Level D disposable PPE (latex rubber gloves), decontamination supplies, and miscellaneous field supplies. Table 4-6 presents the costs for supplies and materials.

The total cost of Soil Rescue reported by Star Organics for Case 1 was $75. 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 a lid, sieves, and shipping containers. Sampling supplies cost approximately $200 for Case 1. Field supplies include water for personnel, a cooler, field notebooks, an outdoor canopy, and other miscellaneous supplies. Field supplies cost an estimated $200. Total costs for supplies and materials 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 Soil Rescue. Assuming a linear cost-to-volume ratio, the total cost of Soil Rescue for Case 2 is estimated to be approximately $12,100. Because Case 2 represents a more extensive 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. The costs of PPE and decontamination supplies are estimated at 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. The total cost for supplies for Case 2 therefore is approximately $14,200.

**Table 4-6.** Supplies and Materials Costs

| Cost Category | Case 1 | Case 2 |
|---|---|---|
| Soil Rescue fluid | $100 | $12,100 |
| Sampling supplies | $200 | $400 |
| PPE and decontamination supplies | $500 | $800 |
| Miscellaneous field supplies | $200 | $900 |
| Total Supplies and Materials Costs | $1,000 | $14,200 |

Note: 1998 dollars.

### 4.3.7 Utilities Costs

Electric utility connections are not required for the application of Soil Rescue. However, because of the manner in which Soil Rescue is applied, a small amount of electricity is needed to pump the solution from the storage tank. This electricity can be provided by a portable generator, making it unnecessary to incur electrical utility costs. The cost of fuel to run the generator and other rental equipment is negligible and is not included in the estimate. Water is required for decontamination of personnel and equipment. Water and other utility costs were insignificant and therefore are not included in the estimate.

### 4.3.8 Effluent Treatment and Disposal Costs

No effluent is produced during the application of Soil Rescue.

### 4.3.9 Residual Waste Shipping and Handling Costs

One of the key features of Soil Rescue is that it does not produce significant amounts of residual waste. Residual wastewater is generated during decontamination of equipment and personnel. For Case 1, the amount of residual wastewater was negligible. OEPA determined that the residual wastewater would not have further effect on the soil or groundwater at 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 Soil Rescue 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 of as solid waste. The owner of the property provided a dumpster for the disposal of the waste. Therefore, no costs for disposal of residual waste are included in the estimate for Case 1.

For Case 2, it is assumed that one 55-gallon drum of residual wastewater will be generated during decontamination activities. For the cost estimate, it is assumed that the disposal cost is $500 per 55-gallon drum. It also is assumed that one 55-gallon drum of nonhazardous solid waste will be generated. The disposal cost for nonhazardous solid waste is estimated at $500 per 55-gallon drum. Therefore, the total estimated cost for disposal

of residual waste for Case 2 is $1,000. If the residual solid waste were hazardous, disposal costs likely would 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 site-specific. Therefore, the costs presented in this analysis may not be applicable to other sites. In total, 292 samples were collected at the CRPAC demonstration site, including 145 samples of untreated soil and 147 samples of treated soil. The large number of samples were taken to ensure that it would be possible the to evaluate how well the stringent objectives of the demonstration had been met.

For Case 1, which is a demonstration-sized or pilot-scale application of the technology, fewer samples are needed. It is assumed that one composite sample will be taken from each of the 11 plots during the sampling of both untreated and treated soil, for a total of 22 samples for Case 1. It also is assumed that, for both cases, the TCLP will be the only parameter analyzed for, since that parameter will determine whether the treatment has reduced concentrations of metals to levels lower than those established under regulatory requirements levels. The average unit cost per sample for the TCLP analyses performed for the SITE demonstration is $73, including the costs of analytical services for standard QA/QC samples. Since the site characteristics for both cases are assumed to be identical to those of 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. 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 (mg/L)2] of concentrations of lead in treated soil at the Case 2 site. It was assumed that the data set could be described adequately by a normal distribution. A hypothesis test was established to compare the treated concentration with 7.5 mg/L (the alternative UTS for lead in soil and the regulatory action level), with the null hypothesis stating that the average concentration in treated soil is greater than 7.5 mg/L.

Calculations of sample are based on use of the one sample t-test statistic. The following equation was used to determine the appropriate number of samples.

$$n = VAR(\Delta)[(Z_{\alpha} + Z_{\beta})/\delta^2]$$

where

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

$\delta$ = Minimum detectable difference from the alternative UTS

$Z_{\alpha}$ = Value from standard normal such that a is the area under the curve to the right of this value

$Z_{\beta}$ = Value from standard normal such that b is the area under the curve to the left of this value

The variables $\alpha$ and $\beta$ are probabilities associated with Type I and Type II errors, respectively. For the analysis, an $\alpha$ level of 0.1 was defined as acceptable to meet the goals of the study. A $\beta$ level of 0.1 was used with a minimum detectable difference (*) of 0.2 mg/L. Values for $Z_{\alpha}$ and $Z_{\beta}$ were obtained from a table of standard normal values.

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. 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 Soil Rescue can be rented. That option, coupled with the fact that the technology can be applied in a short period of time, eliminates the need for maintenance of equipment. Therefore, no maintenance costs are included in the analysis. It may be necessary to consider equipment maintenance costs for projects other than the two cases considered in the analysis, depending on the volume of soil to be treated, the soil conditions, and the length of time necessary to treat the contaminated soil.

### 4.3.12 Site Demobilization Costs

Site demobilization costs consist of demobilizing personnel and transporting materials from the site. Table 4-7 presents the costs for site demobilization. For both cases, it is assumed that some equipment and materials are transported by a medium-duty truck from the CRPAC to the office of Star Organics in Dallas, Texas. The distance between the CRPAC site in Roseville, Ohio, and Dallas, Texas, is approximately 1,100 miles. Star Organics

| Table 4-7. Site Demobilization Costs | | |
|---|---|---|
| Cost Category | Case 1 | Case 2 |
| Mileage | $300 | $300 |
| Labor (40 hours total) ($54/hr x 20 hrs x 2 workers) | $2,200 | $2,200 |
| Per diem ($80/worker/day x 3 days x 2 workers) | $480 | $480 |
| Total Demobilization Costs | $3,000 | $3,000 |
| Note: 1998 dollars. | | |

demobilized two field personnel and one truck. It is assumed that, for Case 2, two personnel and one truck also will be demobilized. Assuming the standard government mileage reimbursement rate of 31 cents per mile, mileage costs from the CRPAC site to Dallas, Texas, are approximately $300. The drive from the CRPAC site to Dallas, Texas, requires approximately 20 hours of driving time. Labor costs for demobilizing two personnel (for a total of 40 hours of labor) earning an estimated labor rate of $54 per hour are approximately $2,200. 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 demobilization cost for both cases is approximately $3,000. Demobilization 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 could be flown to the next site. Such options should be explored to minimize the cost of demobilization.

## 4.4 SUMMARY OF THE ECONOMIC ANALYSIS

Two cost estimates are presented for applying Soil Rescue to remediate soil contaminated with lead in the CRPAC. Both cases are based directly on the costs of 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 one-acre site at which conditions are 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 the analysis for both cases.

For Case 1, important cost categories include site preparation (10.94 percent), mobilization (23.44 percent), equipment (2.34 percent), labor (42.97 percent), supplies and materials (7.81 percent), and analytical services (12.50 percent). No costs were incurred in the other cost categories (permitting and regulatory, utilities, effluent treatment and disposal, residual waste shipping and handling, equipment maintenance, and site demobilization) for Case 1. For Case 2, important cost categories included labor (21.54 percent), supplies and materials (41.85 percent), and analytical services (12.92 percent). The costs for site preparation (4.62 percent), mobilization (9.23 percent), equipment (2.15 percent), residual waste shipping and handling (3.08 percent), and site demobilization (9.23 percent) were also significant for Case 2. No costs were incurred in the other cost categories (permitting and regulatory, utilities, effluent treatment and disposal, and equipment maintenance) for Case 2.

# Section 5
# Technology Status

Since the SITE demonstration projects, Star Organics has conducted several bench-scale treatability studies of Soil Rescue on a variety of soils and wastes contaminated with antimony, arsenic, cadmium, chromium, lead, selenium, and thallium. The studies have included testing of Soil Rescue's ability to treat oil refinery wastes contaminated with heavy metals, metal processing waste, soil at a manufacturing facility that was contaminated with lead, and mine tailings (Star Organics 2000).

## Remediation of Refinery Waste

Testing was conducted to determine whether Soil Rescue could reduce the leachable concentrations of heavy metals in wastes from oil refining processes, including spent catalyst, accumulations of tank bottom sludges, contaminated soil from oil spills or releases, and miscellaneous oil saturated waste. These wastes were treated with thermal desorption, and the ash material was treated with Soil Rescue to reduce concentrations of leachable heavy metal concentrations to levels lower than the UTS. Soil Rescue also was applied to the waste streams before thermal processing. According to Star Organics, Soil Rescue successfully reduced concentrations of leachable heavy metals in the waste streams to levels lower than the UTS (Star Organics 2000).

## Remediation of Metal Processor Waste

Star Organics conducted studies on a waste generated by a metal processing firm that recovers metal from scrap. The primary heavy metal of concern for the waste was lead. Star Organics determined that Soil Rescue could reduce the concentration of leachable lead to meet the UTS.

## *In Situ* Remediation of a Manufacturing Facility

Star Organics conducted several tests on soil contaminated with lead at an abandoned manufacturing site. One test included evaluation of Soil Rescue's ability to reduce the concentration of leachable lead to less than 5.0 mg/L and confirmation of the results through a third-party evaluation of the samples of the soil treated with Soil Rescue. Star Organics claims that Soil Rescue was successful in meeting the project goal and that the results were confirmed through third-party test results.

# Section 6
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# Appendix A
# Vendor Claims

## A.1 Introduction

Star Organics L.L.C.'s Soil Rescue technology is designed to stabilize toxic metals in soils, sludges, and other waste streams, permanently binding the metals and rendering them inactive or unleachable. The technology is applied as a fluid and utilizes one or more techniques depending on the medium being treated and the conditions required to achieve intimate contact of the fluid with the medium of concern.

## A.2 Technology Overview

The technology utilized by Star Organics is chemical complexation, whereby unstabilized metals are bound in a multidentate coordination bond with phosphoryl organic compounds, thereby stabilizing the metal. The technology is not limited to RCRA metals, nor is it limited to soils as the current name of the product implies. It has been tested and found to be effective on metals of concern in the oil field, such as barium, and possibly sodium (more testing is being done as this is written). It has also been tested on antimony, thallium, selenium, arsenic (limited results to date), copper, zinc, and cadmium. The efficiency of the treatment varies depending on the target metal, competing metals, and pH of the medium to be treated. The technology can be applied to media such as wastewater treatment sludges, flyash, mine tailings, and municipal landfill leachates in addition to soils. The Company has also tested the technology on non-toxic metals related to agriculture, turf farms, and golf courses, utilizing the metal stabilization properties of the technology to reduce soil hardness and alkalinity which are known to retard the growth of crops, commercial turf, putting greens, and other vegetation.

## *A.3 Theory of Metals Complexation*

The theory behind the Star Organics technology demonstrated in this SITE program evaluation pertains to the bonding relationships in metal complexes. Chemical elements interact to achieve low (stable) energy conditions when the physical and chemical environments (available complexing agents, pH, intimate contact) permit it.

A metal complex consists of a central ion and ligands. The central ion is a metallic cation (such as lead) about which a definite number of ions or molecules are attached in a preferred geometric arrangement. The molecules or ions attached to the central ion are called ligands. The ligands are classified as monodentate or polydentate, depending on the number of atoms in the ligand which are attached directly to the central atom.

Metal complexes can be formed by anions, some molecules, and very few cations. Star Organics manufactures an organic-based solution containing carboxylic acids and phosphoryl esters, among other compounds, which are known to have properties suitable for the formation of coordination covalent bonds characteristic of those formed in metal complexes.

## A.4 Advantages of Star Organics' Remediation Technology

- In-situ application
- Low labor cost
- No concrete cost
- No incineration cost
- No offsite disposal cost
- No toxic reaction products
- No air pollution issues
- No volume increase when treating wastes
- Limited disposal concerns; disposable coveralls and shoe coverings of application personnel
- No special handling requirements; fluid is non-toxic and non-hazardous
- Few access limitations to the potential site since large dirt handling equipment is not required

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