United States Environmental Protection Agency
Office of Emergency and Remedial Response Washington, D.C. 20460
EPA/540/2-91/020A
September 1991

Superfund

EPA

Guide for Conducting Treatability Studies Under CERCLA:

Soil Washing

Interim Guidance

EPA/540/2-91/020A
September 1991

GUIDE TO CONDUCTING TREATABILITY STUDIES UNDER CERCLA: SOIL WASHING

INTERIM GUIDANCE

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and

Office of Emergency and Remedial Response
Office of Solid Waste and Emergency Response
U.S. Environmental Protection Agency
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DISCLAIMER

This material has been funded wholly or in part by the United States Environmental Protection Agency (EPA) under contract No. 68-C8-0061, Work Assignment No. 2-06, to Science Applications International Corporation (SAIC). It has been subject to the Agency's peer and administrative reviews and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. 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. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory (RREL), is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This document provides guidance for planning, implementing, and evaluating soil washing treatability tests to support the remedy evaluation process for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites. Additionally, it describes a three-tiered approach, which consists of 1) remedy screening, 2) remedy selection, and 3) remedy design, to soil washing treatability testing. It also presents a guide for conducting treatability studies in a systematic and stepwise fashion to determine the effectiveness of soil washing in remediating a CERCLA site. The intended audience for this guide comprises Remedial Project Managers (RPMs), On-Scene Coordinators (OSCs), Potentially Responsible Parties (PRPs), consultants, contractors, and technology vendors.

E. Timothy Oppelt, Director
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ABSTRACT

Systematically conducted, well-documented treatability studies are an important component of the remedial investigation/feasibility study (RI/FS) process and the remedial design/remedial action (RD/RA) process under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). These studies provide valuable site-specific data necessary to aid in the selection and implementation of the remedy. This manual focuses on soil washing treatability studies conducted in support of remedy selection prior to developing the Record of Decision (ROD).

This manual presents guidance for designing and implementing a soil washing treatability study. The manual gives an overview of general information for determining whether soil washing technology may be effective, guidance on designing and conducting soil washing treatability studies for remedy selection, assistance in interpreting data obtained from remedy selection treatability studies, and guidance for estimating costs associated with remedy design and full-scale soil washing remedial action.

The manual is not intended to serve as a substitute for communication with experts or regulators nor as the sole basis for the selection of soil washing as a particular remediation technology. Soil washing must be used in conjunction with other treatment technologies since it generates residuals. This manual is designed to be used in conjunction with the Guide for Conducting Treatability Studies Under CERCLA (Interim Final).[15] The intended audience for this guide comprises Remedial Project Managers (RPMs), On-Scene Coordinators (OSCs), Potentially Responsible Parties (PRPs), consultants, contractors, and technology vendors.

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ACKNOWLEDGMENTS

This document was prepared for the U.S. Environmental Protection Agency, Office of Research and Development, Risk Reduction Engineering Laboratory (RREL), Cincinnati Ohio, by Science Applications International Corporation (SAIC), with the support of its subcontractors, Bruck, Hartman & Esposito, Inc., and Chapman, Inc., under Contract No. 68-C8-0061. Mr. Mike Borst and Ms. Malvina Wilkens served as the EPA Technical Project Monitors. Dr. Thomas Fogg and Mr. Jim Rawe were SAIC's Work Assignment Managers. The project team included Kathleen Hurley, Curtis Schmidt, Cynthia Eghbalnia, and Yueh Chuang of SAIC; Pat Esposito of Bruck, Hartman & Esposito, Inc.; and James Nash of Chapman, Inc. Dr. Robert Shokes and Mr. Clyde Dial served as SAIC's Senior Reviewers, and Robert Coleman served as Technical Editor.

The following Agency and Contractor personnel have contributed their time and comments by participating in the protocol workshop and/or peer reviewing the draft document:

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The document was also reviewed by the Office of Waste Programs Enforcement and the Technology Innovation Office. We sincerely hope we have not overlooked anyone who participated in the development of this guide.

SECTION 1
INTRODUCTION

1.1 BACKGROUND

Section 121 (b) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) mandates the Environmental Protection Agency (EPA) to select remedies that "utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable" and to prefer remedial actions in which treatment that "permanently and significantly reduces the volume, toxicity, or mobility of the hazardous substances, pollutants, and contaminants is a principal element." Treatability studies provide data to support treatment technology selection and remedy implementation. If treatability studies are used, they should be performed as soon as it is evident that insufficient information is available to support the remedial decision. Conducting treatability studies early in the remedial investigation/feasibility study (RI/FS) process reduces uncertainties associated with selecting the remedy and provides a sound basis for the Record of Decision (ROD). EPA Regional planning should factor in the time and resources required for these studies.

Treatability studies conducted during the RI/FS phase indicate whether the technology can meet the cleanup goals for the site. Treatability studies conducted during the remedial design/remedial action (RD/RA) phase establish design and operating parameters for optimization of technology performance. Although the purpose and scope of these studies differ, they complement one another since information obtained in support of remedy selection may also be used to support the remedy design.[24]

This document refers to three levels or tiers of treatability studies: remedy screening, remedy selection, and remedy design. Three tiers of treatability studies are also defined in the Guide for Conducting Treatability Studies Under CERCLA, Interim Final[15], referred to as the "generic guide" hereafter in this document. The generic guide refers to the three treatability study tiers, based largely on the scale of test equipment, as laboratory screening, bench-scale testing, and pilot-scale testing. Laboratory screening is typically used to screen potential remedial technologies and is equivalent to remedy screening. Bench-scale testing is typically used for remedy selection, but may not provide enough information for remedy selection. Bench-scale studies can, in some cases, provide enough information for full-scale design. Pilot-scale studies are normally used for remedial design, but may be required for remedy selection in some cases. Because of the overlap between these tiers, and because of differences in the application of each tier to different technologies, the functional description of treatability study tiers (i.e., remedy screening, remedy selection, and remedy design) has been chosen for this document.

Some or all of the levels may be needed on a case-by-case basis. The need for and the level of treatability testing required are management decisions. The time and cost necessary to perform the testing are balanced against the improved confidence in the selection of treatment alternatives. These decisions are based on the quantity and perceived quality of data available and on other factors (e.g., State and community acceptance of the remedy or new site data on experience with the technology). Section 3 discusses using treatability studies in remedy selection in greater detail.

1.2 PURPOSE AND SCOPE

This guide helps ensure a reliable and consistent approach in evaluating soil washing as a consideration for site remediation. This guide discusses the remedy screening and remedy selection levels of treatability testing. Remedy screening studies provide a quick and relatively inexpensive indication of whether soil washing is a potentially viable remedial technology. The remedy selection treatability test provides data to help determine if reductions in contaminant volumes will allow cost-effective treatment of residual contamination to meet cleanup goals. Remedy selection studies also provide preliminary estimates of the cost and performance data necessary to design either a remedy design study or a full-scale soil washing system.

In general, remedy design studies will also be required to determine if soil washing is a viable treatment alternative for a site. Remedy design studies are conducted after the ROD and are typically vendor-specific. Therefore, remedy design is not discussed in this guidance document.

1.3 INTENDED AUDIENCE

This document is intended for the use of Remedial Project Managers (RPMs), On-Scene Coordinators (OSCs), Potentially Responsible Parties (PRPs), consultants, contractors, and technology vendors. Each has different roles in conducting treatability studies under CERCLA. Specific responsibilities for each can be found in the generic guide.[15]

1.4 USE OF THIS GUIDE

This guide is organized into seven sections, which reflect the basic information required to perform treatability studies during the RI/FS process. Section 1 is an introduction which provides background information on the role of the guide and outlines its intended audience. Section 2 describes different soil washing processes currently available and discusses how to conduct a remedy screening to determine if soil washing is a potentially viable remediation technology. Section 3 provides an overview of the levels of treatability testing and discusses how to determine the need for treatability studies. Section 4 provides an overview of the remedy screening and remedy selection treatability studies, describes the contents of a typical work plan, and discusses the major issues to consider when conducting a treatability study. Section 5 discusses sampling and analysis and quality assurance project plans. Section 6 explains how to interpret the data produced from treatability studies and how to determine if further remedy design testing is justified. Section 7 lists the references.

This guide, along with guides being developed for other technologies, is a companion document to the generic guide. In an effort to limit redundancy, supporting information in the generic guide and other readily available guidance documents is not repeated in this document.

The document is not intended to serve as a substitute for communication with regulators and/or experts in the field of soil washing. This document should never be the sole basis for selecting soil washing as a remediation technology or excluding soil washing from consideration.

As treatability study experience is gained, EPA anticipates further comment and possible revisions to the document. For this reason, EPA encourages constructive comments from outside sources. Direct written comments to:

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SECTION 2
TECHNOLOGY DESCRIPTION AND PRELIMINARY SCREENING

This section presents a description of various full-scale soil washing technologies and a discussion of the information necessary for prescreening the technology before committing to a treatability test program. Subsection 2.1 describes several full-scale soil washing systems. Subsection 2.2 discusses the literature and data base searches required, the technical assistance available, and the review of field data required to prescreen these technologies. Technology limitations are also reviewed in this subsection.

2.1 TECHNOLOGY DESCRIPTION

Soil washing is a physicallchernical separation technology in which excavated soil is pretreated to remove large objects and soil clods and then washed with fluids to remove contaminants. To be effective, soil washing must either transfer the contaminants to the wash fluids or concentrate the contaminants in a fraction of the original volume, using size separation techniques.[12] In either case, soil washing must be used in conjunction with other treatment technologies. Either the washing fluid or the fraction of soil containing most of the contaminant, or both, must be treated. Figure 2-1 presents a schematic diagram of a soils washing process.[12]

The first stage in the soil washing process is preparation of the excavated soil. Soil preparation involves mechanical screening of the soil feedstock to remove debris such as rocks, roots, etc. The maximum size of particles allowed

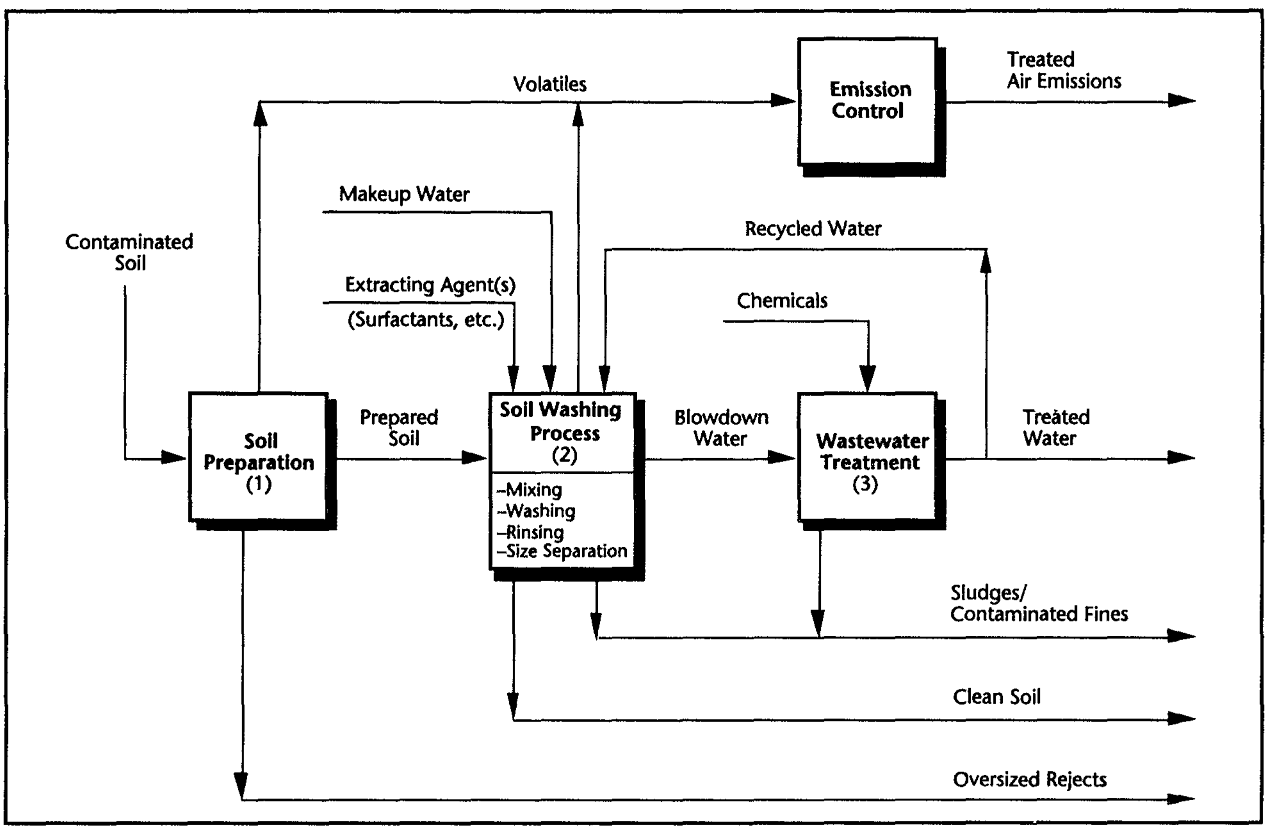


Figure 2-1. Schematic diagram of the major elements of the aqueous soil washing process.

in the feedstock varies with the equipment used, ranging from 10 mm (3/8 inch) up to 50 mm (2 inches).

The next stage is the soil washing process. Typically, soil washing involves mixing, washing, rinsing, and size separation steps. During mixing, the wash fluid is introduced to the soil in measured proportions. At some installations, this is a separate step. Other installations combine mixing and washing into one step (as shown in Figure 2-1).

The intimate energetic mixing of the wash fluid with soil constitutes the "washing" step. Intensive contact between the soil grains and the wash fluid causes the soil contaminants to dissolve and disperse into the water. Energy is introduced into the mixture by high-pressure water jets, vibration devices, and other means, depending upon the equipment.

After the appropriate contact time, treated soil is separated from the wash water. Coarse soil particles are separated with a trammel or vibrating screen device. Fine particles are separated in a sedimentation tank, sometimes with the addition of flocculating agents. Silt is removed in a hydrocyclone or centrifuge device. The coarse soil fraction is rinsed with clean water to remove residual contaminants and fine soil particles which may stiff be adhering to coarse particles. The coarse fhaction is recovered from the process as clean soil.

The final steps treat the remaining fine soils (fine silt and clay) and the contaminated water mixture. The contaminated water mixture may require precipitation and clarification to remove the metals and fine soils as a sludge. If organic contaminants are present, the clarifier effluent may require treatment, typically using activated carbon, before recycling. The fine soils, in which contaminants have been concentrated, will normally require further treatment. If contaminants are volatile, emission controls may be required.

In actual operation, there are more sidestreams and equipment involved than shown in the Figure 2-1. This equipment typically includes soil feedstock and treated soil conveyors and earthmoving equipment for stockpiling soil. This equipment is, however, ancillary and not critical to understanding the basic soil washing process.

2.1.1 Soil Washing by Phase Transfer

During soil washing, some contaminants dissolve or become suspended in the aqueous wash fluid and are removed for further treatment. If the washed soil meets the established cleanup goals in the ROD, it may be returned to the original excavation site. If unacceptable levels of contaminants remain, the soil should be stockpiled or fed directly to the next step for additional treatment.

Chemical agents may be added to the wash water to increase the efficiency of contaminant removal. Acids, such as hydrochloric acid, sulfuric acid, and nitric acid, may be added to improve the solubility of certain contaminants, especially heavy metals. Sodium hydroxide, sodium carbonate, and other bases can be used to precipitate contaminants in the extraction fluid. Clay and humus fractions, which may contain a large percentage of organic contaminants, are dispersed by bases.[10] Dispersion of oily contaminants can be facilitated by the addition of surface active agents. Various chelating or sequestering agents, such as citric acid, ammonium acetate, nitrilotriacetic acid (NTA), and ethylenediaminetetraacetic acid (EDTA), will remove the available fraction of inorganic contaminants. Combining chemicals may improve process performance in some cases, although limited information is available on the performance of these combinations. Contaminant removal may be improved, in certain cases, by elevation of the extraction temperature or by chemical oxidation of the contaminants using an oxidizer (e.g., hydrogen peroxide or ozone).[3]

2.1.2 Soil Washing Using Particle Size Separation

EPA research shows that a large percentage of soil contamination (especially organic) is sometimes associated with, or bound to, very small (silt and clay) soil particles. In these situations, a physical separation of the large soil particles (sand and gravel) from the silt, clay, and humic material effectively concentrates the contaminants. Soil washing significantly reduces the volume of contaminated soil when this condition occurs. Following mixing and washing, sand particles larger than 50 to 80 μm can be easily separated from the washing fluid because of their relatively high settling velocity. Simple, inexpensive equipment, such as settling chambers, can be used.

Most of the clay particles and humus remain suspended in the wash water supernatant after sand and gravel sedimentation. These small, slow-settling particles pass through the settling chambers. They ultimately end up in the wastewater treatment sludge.[3]

2.1.3 Use In Conjunction With Other Treatment Technologies

Soil washing is not usually a stand-alone technology. Typically, both the fine soils (silts and clays) recovered after washing and the spent wash water are subject to further specific treatment and disposal techniques, as appropriate, to complete the cleanup. Wash water is normally treated using standard wastewater treatment practices. Sludges generated during wash water treatment may need subsequent treatment by such methods as solidification/stabilization, biodegradation, and incineration. The EPA document entitled, "Technology Screening Guide for Treatment of CERCLA Soils and Sludges," contains a detailed description of potential treatment technologies.[22] Sidestreams generated during treatment, such as spent solvents, exhausted resins, air emissions, etc., must also be treated.

2.2 PRELIMINARY SCREENING AND TECHNOLOGY LIMITATIONS

The need for and the appropriate level of treatability studies required are dependent on available literature, expert technical judgment, and site-specific factors. The first two elements--the literature search and expert consultation--are critical factors in determining if adequate data are available or whether a treatability study is needed to provide those data.

2.2.1 Literature/Data Base Review

Several reports and electronic data bases exist which should be consulted to assist in planning and conducting treatability studies, and to help prescreen soil washing for use at a specific site. Existing reports include:

- Guide for Conducting Treatability Studies Under CERCLA, Interim Final. U.S. Environmental Protection Agency, Office of Research and Development and Office of Emergency and Remedial Response, Washington, D.C. EPA/540/2-89/058, December 1989.

- Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA, Interim Final. U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, D.C. EPA/540/G-89/004, October 1988.

- Superfund Treatability Clearinghouse Abstracts. U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, D.C. EPA/540/2-89/001, March 1989.

- The Superfund Innovative Technology Evaluation Program: Technology Profiles. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response and Office of Research and Development, Washington, D.C. EPA/540/5-90/006, November 1990.

- Summary of Treatment Technology Effectiveness for Contaminated Soil. U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, D.C., 1989 (in press).

- Technology Screening Guide for Treatment of CERCLA Soils and Sludges. U.S. Environmental Protection Agency. EPA/540/2-88/004, 1988.

- U.S. Environmental Protection Agency, Applications Analysis Report - CF Systems Organics Extraction System, New Bedford, MA, EPA Report to be published.

Currently, RREL in Cincinnati is expanding its Superfund Treatability Data Base. This data base will contain data from all treatability studies conducted under CERCLA. A repository for treatability study reports will be maintained at RREL in Cincinnati. The contact for this data base is Glenn Shaul at (513) 569-7408.

Office of Research and Development (ORD) headquarters maintains the Alternative Treatment Technology Information Center (ATTIC), a comprehensive, automated information retrieval system that integrates hazardous waste data into a unified, searchable resource. The intent of ATTIC is to provide the user community with technical data and information on available alternative treatment technologies and to serve as an initial decision support system. Since ATTIC functions as a focal point for users, it facilitates the sharing of information with the user community and creates an effective network of individuals and organizations involved in hazardous waste site remediation.

The information contained in ATTIC consists of a wide variety of data obtained from Federal and State agencies. The core of the ATTIC system is the ATTIC Data Base, which contains abstracts and executive summaries from over 1,200 technical documents and reports. Information in the ATTIC Data Base has been obtained from the following sources:

- The Superfund Innovative Technology Evaluation (SITE) Program

- California Summary of Treatment Technology Demonstration Projects

- Data collected for the Summary of Treatment Technology Effectiveness for Contaminated Soil

- North Atlantic Treaty Organization (NATO) International Data

- Innovative Technologies Program Data

- Removal Sites Technologies Data

- Resource Conservation and Recovery Act (RCRA) Delisting Actions

- USATHAMA Installation Restoration and Hazardous Waste Control Technologies

- Records of Decision (from 1988 on)

- Treatability Studies

- Superfund Treatability Data Base (also available through ATTIC)

In addition, the ATTIC system contains a number of resident data bases that have been previously developed, as well as access to on-line commercial data bases. For more information, contact the ATTIC System Operator at (301) 816-9153.

The Office of Solid Waste and Emergency Response (OSWER) maintains an Electronic Bulletin Board System (BBS) as a tool for communicating ideas and disseminating information and as a gateway for other Office of Solid Waste (OSW) electronic data bases. Currently, the BBS has eight different components, including news and mail services and conferences and publications on specific technical areas. The contact is James Cummings at (202) 382-4686.

2.2.2 Technical Assistance

Technical assistance can be obtained from the Technical Support Project (TSP) team, which is made up of six Technical Support Centers and two Technical Support Forums. It is a joint service of the Office of Solid Waste and Emergency Response, the Office of Research and Development, and the Regions. The TSP offers direct site-specific technical assistance to On-Scene Coordinators (OSCs) and RPMs and develops technology workshops, issue papers, and other information for Regional staff. The TSP:

- Reviews contractor work plans, evaluates remedial alternatives, reviews RI/FS, and assists in the selection and design of the final remedy

- Offers modeling assistance and data analysis and interpretation

- Assists in developing and evaluating sampling plans

- Conducts field studies (soil gas, hydrogeology, site characterization)

- Develops technical workshops and training, issue papers on groundwater topics, and generic protocols

- Assists in performing treatability studies.

The following support centers provide technical information and advice related to soil washing and treatability studies:

1. GroundwaterFate and Transport Technical Support Center

Robert S. Kerr Environmental Research Laboratory (RSKERL), Ada, Oklahoma
Contact: Don Draper
FTS 743-2202 or (405) 332-8800

RSKERL in Ada, Oklahoma, is EPA's center for fate and transport research. It focuses its efforts on transport and fate of contaminants in the vadose and saturated zones of the subsurface, methodologies relevant to protection and restoration of groundwater quality, and evaluation of subsurface processes for the treatment of hazardous waste. The Center provides technical assistance, such as evaluating remedial alternatives; reviewing RI/FS and RD/RA work plans; and providing technical information and advice.

2. Engineering and Treatment Technical Support Center

Risk Reduction Engineering Laboratory (RREL), Cincinnati, OH
Contact: Ben Blaney
FTS 648-7406 or (513) 569-7406

The Engineering and Technical Support Center (ETSC) is sponsored by OSWER but operated by RREL. The center handles site-specific remediation engineering problems. Access to this support Center must be obtained through the EPA Remedial Project Manager.

RREL offers expertise in contaminant source control structures; materials handling and decontamination; treatment of soils, sludges and sediments; and treatment of aqueous and organic liquids. The following are examples of the technical assistance that can be obtained through ETSC:

- Screening of treatment alternatives

- Review of the treatability aspects of RI/FS
- Review of RI/FS treatability study Work Plans and final reports
- Oversight of RI/FS treatability studies
- Evaluation of alternative remedies
- Assistance with studies of innovative technologies
- Assistance in full-scale design and start-up

2.2.3 Prescreening Characteristics

The need for a treatability study is determined near the beginning of the RI/FS when a literature survey of remedial technologies is performed. Remedial technologies are identified based on compatibility with the type of contaminants and the media (soil, water, etc.) present at the site, and the anticipated cleanup objectives. Remedial technologies are prescreened for effectiveness, implementability, and cost. The prescreening is done using available technical literature, data bases and manufacturer's information. Based on this initial technology prescreening, soil washing may be one of several candidate remedial technologies eliminated before or during the RI/FS. See the generic guide for more specific details on screening of treatment technologies and on determining the need and type of treatability tests which may be required for evaluating treatment technology alternatives.[15]

Prescreening activities for soil washing treatability testing include interpreting any available site-related field measurement data. The purpose of prescreening is to gain enough information to eliminate from further treatability testing treatment technologies that have little chance of achieving the cleanup goals.

Table 2-1 lists physical parameters that may be measured or available before designing treatability tests. Particle size distribution and cation exchange capacity (CEC) measurements are particularly useful when evaluating soil washing.

If contamination exists at different soil zones, a soil characterization profile should be developed for each soil type or zone. Available chemical and physical data (including averages and ranges) and the volumes of the contaminated soil requiring treatment should be identified. Hot spots require separate characterizations so they can be properly addressed in the treatability tests. Soil washing may be applicable to some, but not all, parts of a site.

Characterization test results should be broadly representative of the waste profile of the site. Grab samples taken from the site ground surface may represent only a small percentage of the contaminated soils requiring remediation. Deeper, subsurface strata affected by contaminants may vary widely in composition (grain size, clay content, cation exchange capacity, total organic carbon, and contamination levels) from those found at the surface and should also be characterized. If significant sand or clay lenses are present in the contaminated zone, the location and volume should be estimated. This information is critical to determine the mix of feedstocks to be used. The quantity and distribution of rubble and debris should also be determined as part of the characterization. This material must be removed from the feedstock material during any full-scale treatment operations. In general, existing commercial soil washers cannot accept material larger than 3/8 to 2 (10 to 50 mm) inches in diameter.

The three most important soil parameters to be evaluated during prescreening and remedy screening tests are the *grain size distribution*, *clay content*, and *cation exchange capacity*. Soil washing performance is closely tied to

TABLE 2-1. Physical Prescreening Soil Characterization Tests

Parameter	Description of Test	Standard Analytical Method	Reference
Grain size analysis/ particle size distribution	Sieve screening using #10 and #60 screens or equivalent	ASTM D422	1
Cation exchange capacity (CEC)	Ammonium acetate Sodium acetate	Method 9080 Method 9081	23 23

these three factors. Soils with relatively large percentages of sand and gravel (coarse material >2 mm) respond better to soil washing than soils with small percentages of sand and gravel. Larger percentages of clay and silt (fine particles smaller than 0.25 mm) reduce contaminant removal efficiency. In general, soil washing is most appropriate for soils that contain at least 50 percent sand/gravel, i.e., coastal sandy soils and soils with glacial deposits. Soils rich in clay and silt tend to be poor candidates for soil washing. Cation exchange capacity measures the tendency of the soil to exchange weakly held cations in the soil for cations in the wash solution. Soils with relatively low CEC values (less than 50 to 100 meq/kg) respond better to soil washing than soils with higher CEC values. Early characterization of these parameters and their variability throughout the site provides valuable information for the initial screening of soil washing as an alternative treatment technology. Appendix C of the generic guide lists other specific characterization parameters.(15)

Chemical and physical properties of the contaminant should also be investigated. Solubility in water (or other washing fluids) is one of the most important physical characteristics. Reactivity with wash fluids may, in some cases, be another important characteristic to consider. Other contaminant characteristics such as volatility and density may be important for the design of remedy screening studies and related residuals treatment systems. Speciation, is important in metal-contaminated sites. Specific metal compounds should be quantified rather than total metal concentration for each metal present at the site. Soil prescreening characterization data should be assembled and organized in a concise tabular form before designing the remedy screening tests.

2.2.4 Soil Washing Limitations

Soil washing limitations may be defined as characteristics that hinder cost-effective soil treatment. The limitation may be due to the soil particle distribution (high percentage of silt, clay, or organic matter), the contaminant (high concentration of mineralized metals or hydrophobic organics), or the process itself. High concentrations of additives may be required in some cases to meet the necessary performance goals. Difficulties are sometimes encountered in treating and recycling additives in the spent wash water. If these conditions occur, process costs may be prohibitive due to the cost of treating washing fluids and replenishing additives.

Hydrophobic contaminants can be difficult to separate from soil particles into the aqueous washing fluid. Estimated aqueous distribution coefficients (K_d), also known as partition coefficients.(K_p), indicate the fraction of the contaminant expected to remain on the soil particle versus the fraction of the contaminant dissolved in the water. (6) Alternative methods can be used to estimate these values when tabulated values cannot be located.(8) A contaminant with a high K_d (e.g., PCB > 10,000) is more difficult to wash off the soil particles using water than a contaminant with a lower K_d (e.g., TCE=3). Additives such as surfactants may be required to improve removal efficiencies. However, larger volumes of washing fluid may be needed when additives are used.

Complex mixtures of contaminants in the soil, such as a mixture of metals, nonvolatile organics, semivolatile organics, etc., make it difficult to formulate a single suitable washing fluid that will remove all the different types of contaminants from the soil. Sequential washing steps, using different additives, may be needed. Frequent changes in the contaminant type and concentration in the feed soil can disrupt the efficiency of the soil washing process. To accommodate changes in the chemical or physical composition of the feed soil, modifications to the wash fluid formulation and the operating settings may be required. Alternatively, additional feedstock preparation steps, such as blending soils to provide a consistent feedstock; may be appropriate.

High humic content in the soil makes separation of contaminants very difficult. Humus consists of decomposed plant and animal residues and offers binding sites for accumulation of both organics and metals. A high percentage of clay and silt (e.g., more than 30 to 50 percent) in the soil usually indicates that soil washing will be unfavorable due to the amount of time and money required to treat this volume of contaminated soil. A volume reduction process like soil washing is most cost-effective when the cleaner soil fraction is much larger than the more contaminated soil fraction.

Chelating agents, surfactants, solvents, and other additives are often difficult and expensive to recover from the spent washing fluid and then recycle in the soils washing process. The presence of additives may make the spent washing fluid difficult to treat by conventional treatment processes such as settling, chemical precipitation, or activated carbon. The presence of additives in the contaminated soil and treatment sludge residuals may cause increased difficulty in disposing of these residuals.

SECTION 3
THE USE OF TREATABILITY STUDIES IN REMEDY EVALUATION

This section presents an overview of the use of treatability tests in confirming the selection of soil washing as the technology remedy under CERCLA. It also provides a decision tree that defines the tiered approach to the overall treatability study program with examples of the application of treatability studies to the RI/FS and remedy evaluation process. Subsection 3.1 presents an overview of the general process of conducting treatability tests. Subsection 3.2 defines the tiered approach to conducting treatability studies and the applicability of each tier of testing, based on the information obtained, to assess, evaluate, and confirm soil washing technology as the selected remedy.

3.1 PROCESS OF TREATABILITY TESTING IN EVALUATING A REMEDY

Treatability studies should be performed in a systematic fashion to ensure that the data generated can support the remedy evaluation process. This section describes a general approach that should be followed by RPMs, PRPs, and contractors during all levels of treatability testing. This approach includes:

- Establishing data quality objectives
- Selecting a contracting mechanism
- Issuing the Work Assignment
- Preparing the Work Plan
- Preparing the Sampling and Analysis Plan
- Preparing the Health and Safety Plan
- Conducting community relations requirements
- Complying with regulatory requirements
- Executing the study
- Analyzing and interpreting the data
- Reporting the results

These elements are described in detail in the generic guide. [15] That document gives information applicable to all treatability studies. It also presents information specific to each of the levels of treatability testing.

Treatability studies for a particular site will often entail multiple tiers of testing. Duplication of effort can be avoided by recognizing this possibility in the early planning phases of the project. The Work Assignment, Work Plan, and other supporting documents should include all anticipated activities.

There are three levels or tiers of treatability studies: remedy screening, remedy selection, and remedy design testing. Some or all of the levels may be needed on a case-by-case basis. The need for and the level of treatability testing required are management decisions in which the time and cost necessary to perform the testing are balanced against the risks inherent in the decision (e.g., selection of an inappropriate treatment alternative). These decisions are based on the quantity and perceived quality of data available and on other decision factors (e.g., State and community acceptance of the remedy or new site data). The flow diagram for the tiered approach in Figure 3-1 traces the stepwise review of data with the decision points and factors to be considered.

Technologies generally are evaluated first at the remedy screening level and progress through remedy selection to the remedy design testing. A technology may enter the selection process, however, at whatever level is appropriate based on available data on the technology and site-specific factors. For example, a technology that has been successfully applied at a site with similar conditions and contaminants may not require remedy screening to determine whether it has the potential to work. Rather, it may

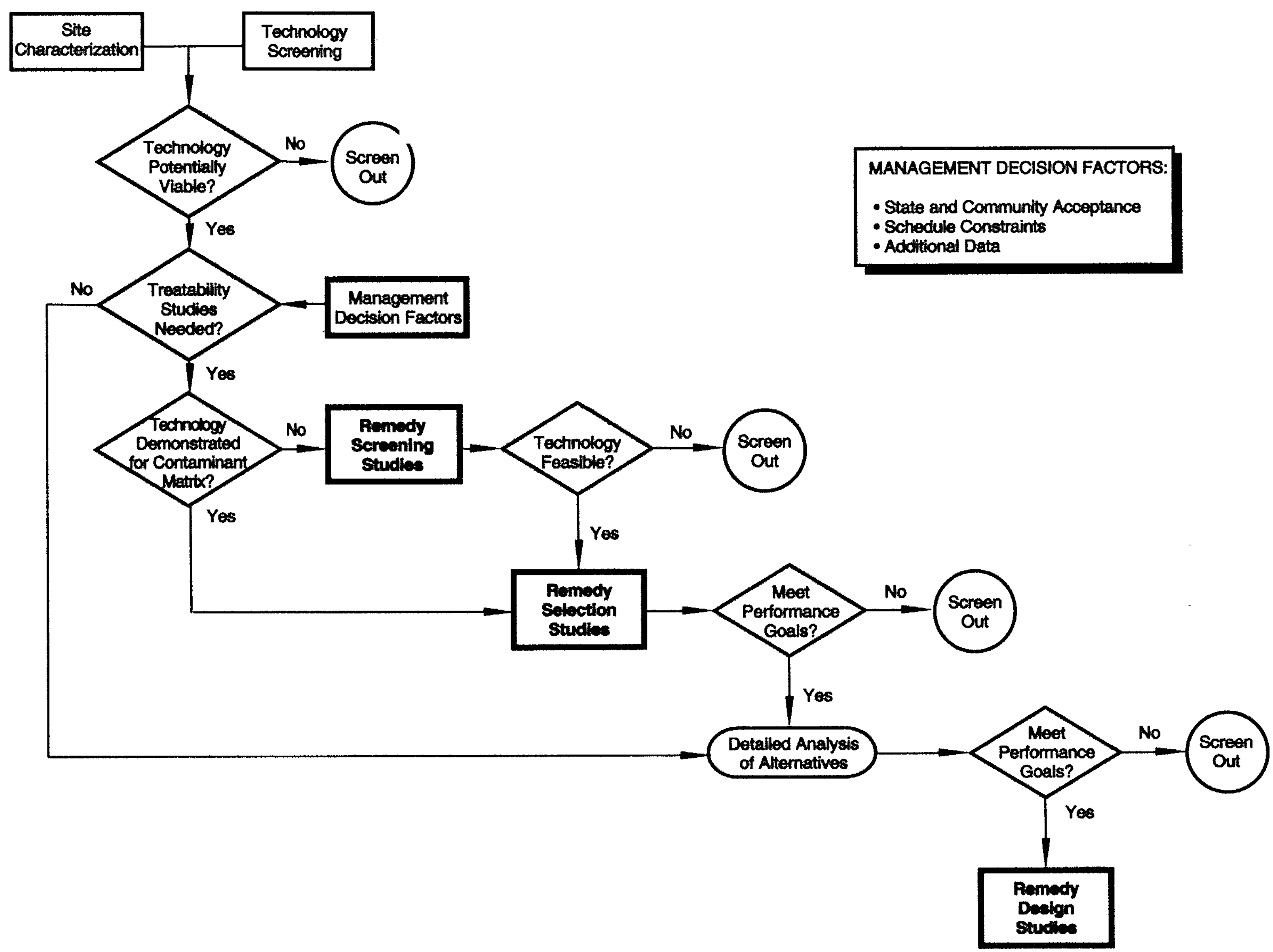


FIGURE 3-1. Flow diagram of the tiered approach.

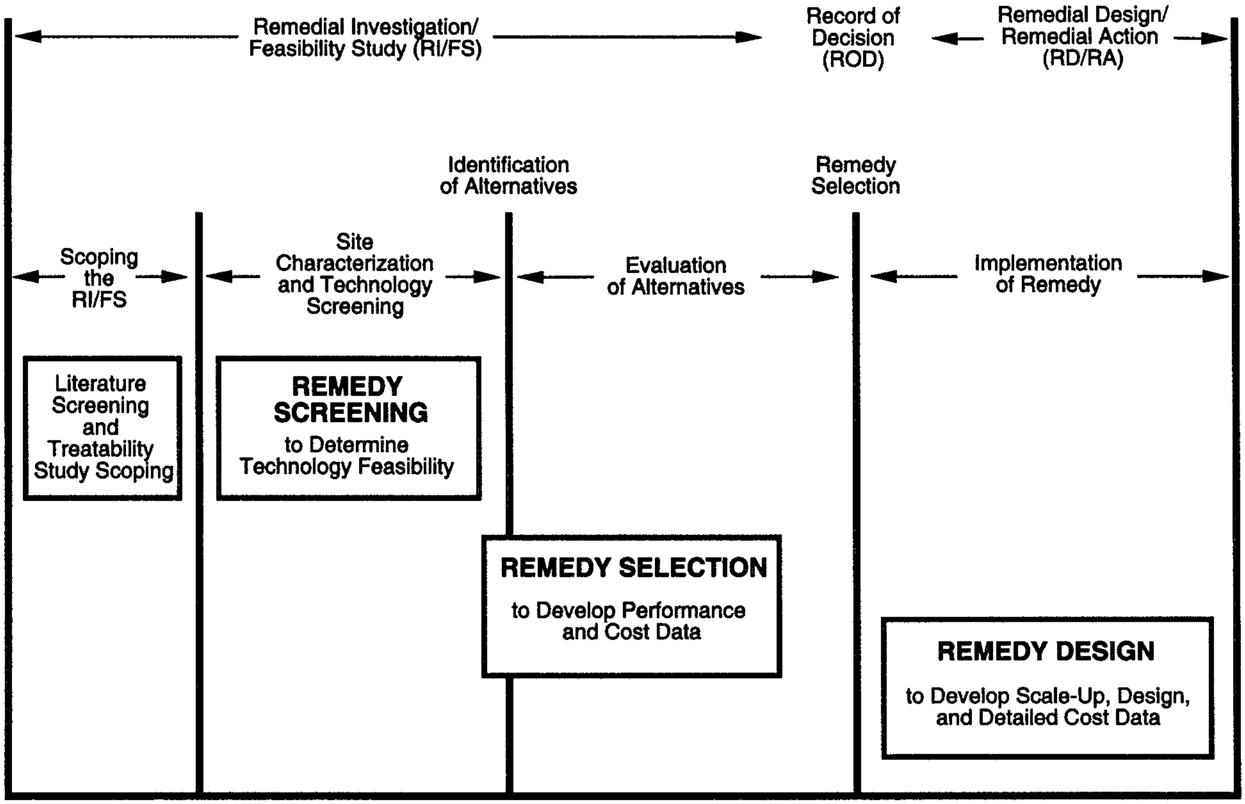


FIGURE 3-2. The role of treatability studies in the RI/FS and RD/RA process.

go directly to remedy selection testing to verify that performance standards can be met and generate preliminary cost estimates. Treatability studies, at some level, will normally be needed to assure that the technology can achieve site target cleanup goals even if previous studies or actual implementation have encompassed similar site conditions. Figure 3-2 shows the relationship of the three levels of a treatability study to each other and to the RI/FS process.

3.2 APPLICATION OF TREATABILITY TESTS

Before conducting treatability studies, the objectives of each tier of testing must be established. Soil washing treatability study objectives are based on the specific needs of the RI/FS. There are nine evaluation criteria specified in the document, Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA (Interim Final);[14] the treatability studies provide data for up to seven of these criteria. These seven criteria are:

- Overall protection of human health and environment
- Compliance with applicable or relevant and appropriate requirements (ARARs)
- Reduction of toxicity, mobility, or volume through treatment
- Short-term effectiveness
- Implementability
- Long-term effectiveness and permanence
- Cost

The first four of these evaluation criteria deal with the degree of contaminant reduction achieved by the soil washing process. What will be the remaining contaminant concentrations? Will the residual contaminant levels be sufficiently low to meet the established ARARs and the risk-based contaminant cleanup levels? What are the contaminant concentration and physical and chemical differences between the untreated and the washed soil fractions (i.e., has contaminant toxicity, mobility, and volume been reduced)? The fourth criterion, short-term effectiveness, addresses the risks posed by the treatment technology during construction and implementation of a remedy.

The implementability assessment evaluates the technical and administrative feasibility of the technology and the availability of required goods and services. The following questions must be answered in order to address the implementability of soil washing:

- What is the percentage of clay, silt, and humic matter requiring additional treatment?
- What additives will be required (e.g., chelating agents or surfactants) that might make residuals treatment and disposal difficult?
- What are the characteristics and the volume of the sludge that will be produced?
- Is sufficient water available at the site, and is it suitable for process use?

Normally, the required equipment and washing solutions are available. However, alterations to process design may be necessary on a site-by-site basis to accommodate different soils and contaminants. Sidestreams and residual soil from the soil washing process require additional treatment. The implernentability assessment must include these additional treatments.

Long-term effectiveness assesses how effective treatment technologies are in maintaining protection of human health and the environment after response objectives have been met. The magnitude of any residual risk and the adequacy and reliability of controls must be evaluated. Residual risk, as applied to soil washing, assesses the risks associated with the treatment residuals at the conclusion of all remedial activities. Analysis of residual risk from sidestream and other treatment train processes should be included in this step. An evaluation of the reliability of treatment process controls assesses the adequacy and suitability of any long-term controls (such as site access restrictions and deed limitations on land use) that are necessary to manage treatment residuals at the site. Such assessments are usually beyond the scope of a remedy selection treatability study, but may be addressed conceptually based on remedy selection results. Performance objectives must consider the existing site soil contaminant levels and relative cleanupgoals for the site. In previous years, cleanup goals often reflected background site conditions, Attaining background cleanup levels through treatment has proven impractical in many situations. The present trend is toward the development of site-specific cleanup target levels that are risk-based rather than based on background levels.

The final EPA evaluation criterion that can specifically be addressed during a treatability study is cost. Soil washing is basically a volume reduction technology that uses wash water to separate contaminated soil into two fractions: a large fraction of relatively clean, coarse soil and a smaller fraction of fine soil/sludge containing the concentrated contaminants.

Remedy selection treatability studies can provide data to estimate the following important cost factors:

- Recoverable clean soil fraction (the achievable volume reduction)
- The volume and characteristics of the concentrated fine soil and sludge fractions requiring treatment or disposal
- The degree to which the additives can enhance the process efficiency
- The degree to which the additives can be recovered and recycled
- The ratio of additives to soil
- The ratio of soil to wash water

The first three factors provide information about the costs of downstream treatments by determining the amount and character of the contaminated residuals. The last three factors help estimate the costs of supplies and utilities.

3.2.1 Remedy Screening

Remedy screening is the first testing level. It establishes the ability of a technology to treat a specific waste. These studies are generally low cost (e.g., $10,000 to $50,000) and usually require hours to days to complete. The lowest level of quality control is required for remedy screening studies. They yield data enabling qualitative assessment of a technology's potential to meet performance goals. Remedy screening tests can identify operating conditions for investigation during remedy selection or remedy design testing. They generate little, if any, design or cost data and should never be used as the sole basis for selection of a remedy.

Soil washing treatability studies are frequently skipped during remedy screening. Often, there is enough information about the physical and chemical characteristics of the soil and contaminant to allow an expert to evaluate the potential success of soil washing at a site. When performed, remedy screening tests are jar tests. However, remedy selection tests are normally the first level of treatability study executed.

3.2.2 Remedy Selection

Remedy selection testing is the second level of testing. Remedy selection tests identify the technology's performance for a site. These studies have a moderate cost (e.g., $20,000 to $100,000) and require several weeks to complete. Remedy selection tests yield data that verify that the technology can meet expected cleanup goals, provide information in support of the detailed analysis of alternatives (i.e., seven of the nine evaluation criteria), and give indications of optimal operating conditions.

The remedy selection tier of soil washing testing typically consists of laboratory tests which provide sufficient experimental controls such that a semi-quantitative mass balance can be achieved. Toxicity testing of the cleaned soil is typically employed in the remedy selection tier of treatability testing. The key question to be answered during remedy selection testing is how much of the soil will be treated by either particle size separation or solubilization to meet the cleanup goal by this process. The exact removal efficiency needed to meet the specified goal for the remedy selection test is site-specific. Pilot-scale tests may be appropriate to support the remedy selection phase for innovative technologies such as soil washing. Typically, a remedy design study would follow a successful remedy selection study.

3.2.3 Remedy Design

Remedy design testing is the third level of testing. It provides quantitative performance, cost, and design information for remediating an operable unit. This testing also produces the remaining data required to optimize performance. These studies are of moderate to high cost (e.g., $ 100,000 to $500,000) and require several months to complete. For complex sites (i.e., sites with different types or concentrations in different areas or with different soil types in different areas), longer testing periods may be required, and costs will be higher. Remedy design tests yield data that verify performance to a higher degree than remedy selection tests and provide detailed design information. They are performed after the ROD during the remedy implementation phase of a site cleanup.

Remedy design tests usually consist of bringing a mobile treatment unit onto the site, or constructing a small-scale (pilot) unit for nonmobile technologies. Permit exclusions may be available for offsite treatability studies under certain conditions. The goal of this tier of testing is to confirm the cleanup levels and treatment times specified in the Work Plan (see Section 4.1.1). This is best achieved by operating a field unit under conditions similar to those expected in the full-scale remediation project.

Data obtained from the remedy design tests are used to:

- Design the full-scale unit
- Refine cleanup time estimates
- Refine cost predictions

Given the lack of full-scale experience with innovative technologies, remedy design testing will generally be necessary to support remedy selection and implementation.

SECTION 4
TREATABILITY STUDY WORK PLAN

Section 4 of this document is written assuming that a Remedial Project Manager is requesting treatability studies through a work assignment/work plan mechanism. Although the discussion focuses on this mechanism, it would also apply to situations where other contracting mechanisms are used.

This section focuses on specific elements of the Work Plan for soil washing treatability studies. The elements include test objectives, experimental design and procedures, equipment and materials, reports, schedule, management and staffing, and budget. These elements are described in Sections 4.1–4.9. Complementing the above subsections are Section 5, Sampling and Analysis Plan, which contains a Field Sampling Plan and a Quality Assurance Project Plan, and Section 6, Treatability Data Interpretation. These sections address the Sampling and Analysis and Data Analysis and Interpretation elements of the Work Plan. Table 4-1 lists the other remaining Work Plan elements

Carefully planned treatability studies are necessary to ensure that the data generated are useful for evaluating the validity or performance of a technology. The Work Plan, prepared by the contractor when the Work Assignment is in place, sets forth the contractor's proposed technical approach for completing the tasks outlined in the Work Assignment. It assigns responsibilities and establishes the project schedule and costs. The Work Plan must be approved by the RPM before initiating subsequent tasks. For more information on each of these sections, refer to the generic guide.[15.]

TABLE 4-1. Suggested Organization of Soil Washing Treatability Study Work Plan

No.	Work Plan Elements	sub-section
1.	Project Description	
2.	Remedial Technology Description	
3.	Test Objectives	4.1
4.	Experimental Design and Procedures	4.2
5.	Equipment and Materials	4.3
6.	Sampling and Analysis	4.4
7.	Data Management	
8.	Data Analysis and Interpretation	4.5
9.	Health and Safety	
10.	Residuals Management	
11.	Community Relations	
12.	Reports	4.6
13.	Schedule	4.7
14.	Management and Staffing	4.8
15.	Budget	4.9

4.1 TEST GOALS

Setting goals for the treatability study is critical to the ultimate usefulness of the data generated. Objectives must be defined before starting the treatability study. Each tier of treatability study needs performance goals appropriate to that tier. For example, remedy selection tests are used to answer the question, "Will soil washing work on this soil/contaminant matrix?" It is necessary to define "work" (i.e., set the goal of the study). A contaminant reduction of approximately 90 percent in the >2 mm soil fraction indicates that further testing for remedy design is appropriate.

The ideal technology performance goals are the cleanup criteria for the site. For several reasons, such as ongoing waste analysis and ARARs determination, cleanup criteria are sometimes not finalized until the ROD is signed, long after treatability studies must be initiated. Nevertheless, treatability study goals need to be established before the study is performed so that the success of the treatability study can be assessed. In many instances, this may entail an educated guess as to what the final cleanup levels may be. In the absence of set cleanup levels, the RPM can estimate performance goals for the treatability studies based on the first four criteria listed on page 11. Previous treatability study results may provide the basis for an estimate of the treatability study goals in this case.

4.1.1 Remedy Screening Goals

Remedy screening tests are not always performed for soil washing processes (see Section 3). If remedy screening tests are performed, an example of the goal for those tests would be to show that the wash fluid will solubilize or remove a sufficient percentage (e.g., 50 percent) of the contaminants to warrant further treatability studies, Another goal might be to show that contaminant concentrations can be reduced by at least 50 percent in the >2 mm soil fraction, using particle size separation techniques.

These goals are only examples. The remedy screening treatability study goals must be determined on a site-specific basis.

Achieving the goals at this tier merely indicates that soil washing has a chance of success and that further studies will be useful. Frequently, such information is available based on the type of soil and contaminant present at the site. Based on such information, experts in soil washing technology can often assess the potential applicability of soil washing without performing remedy screening.

Example 1 describes a hypothetical site and a series of simple jar tests that were used to evaluate the potential to

Example 1. Remedy Screening

An industrial facility in the southeastern United States was built in 1960 and operated until 1990. During that time, various electronic component assembly and electroplating operations were conducted at the site. Between 1960 and 1980, sludges and other process related wastes generated at the plant were buried in onsite landfills. Sometimes, plating/etching solutions and other liquids were disposed of by open dumping onto the ground or into sand-filled pits constructed for this purpose.

As a results of these past practices, soils in several areas at the site are contaminated with heavy metals, namely copper, chromium, lead, nickel, and cadmium. Initial site investigations have shown that the average and maximum sample values for metals found in soil borings are as follows:

Metal	**Average (MgLkg)**	**Maximum**
Copper	2,500	20,000
Lead	1,000	7,500
Chromium	1,200	4,000
Nickel	450	790
Cadmium	75	200

Soil borings at the site have shown that most of the contamination is located 4 to 6 feet below grade. About 5,000 to 10,000 cubic yards of soil are believed to be affected by the metals and volatile organic compounds (VOCs).

Soils were described in the boring logs as clayey sands. A sample of soil, composited from soil borings cuttings from various areas and depths in the contaminated zone, was sent to the lab for dry sieve particle size analysis (ASTM methods); results indicated that 38 to 45 percent of the soil particles are >2 mm in diameter, and 5 to 11 percent are between 1 mm and 2 mm in diameter.

Soil washing was considered as a potential technology to reduce the volume of contaminated soil for two reasons. First, the sieve analysis showed that a large percentage of the soil (38 to 45 percent) was coarse sand or gravel (>2 mm in particle size diameter). This indicated that a large percentage of the soil was likely to respond favorably to soil washing and therefore could be eliminated from further treatment. Research at the EPA and elsewhere has shown that soil washing is typically most effective in removing contaminants from the >2 mm fraction. Second, the large quantity of soil affected by metal contaminants could potentially justify the cost of assembling and operating on onsite washing system.

A series of simple jar tests was conducted on the site using both hot and cold water to wash a composite soil sample that broadly represented soil areas known to be contaminated with metals. Equal quantities of soil and water were placed in a jar, shaken, and then poured across a #10 sieve screen. The particles lying on the top of the sieve were rinsed with water and allowed to drip dry. The dry soil was then placed in a clean, tared sample jar, weighed, and sent to the laboratory for total metal analysis. The tests were repeated three times to measure variability. Average results showed that the soil washed with hot water (>2 mm fraction) responded the best; the average metal concentrations in the soil before and after hot water washing are shown below:

Metal	Soil Concentration Before Washing (i.e., whole soil, mg/kg)	Soil Concentration After Hot Water Washing (i.e., >2 mm fraction, mg/kg)	
Copper	2,000	500	(75% red.)
Lead	1,200	300	(75% red.)
Chromium	800	100	(88% red.)
Nickel	400	50	(88%red.)
Cadmium	50	15	(70% red.)

The test results indicate that metal reductions on the order of 70 to 88 percent are readily achievable with hot water. Product/soil recovery rates on the order of 30 to 50 percent (based on comparison of recovered weights versus starting weight of soil in each test) are achievable. In order to further confirm these initial findings and to maximize the efficiency of the treatment process, bench tests are indicated.

use soil washing to remediate the site. The example illustrates how to decide whether the remedy selection treatability studies using soil washing should be performed.

4.1.2 Remedy Selection Treatability Study Goals

The main objectives of this tier of testing are to:

- Measure the percentage of the contaminant that can be removed from the soil through solubilization or from the >2 mm. soil fraction by particle size separation
- Produce the design information required for the next level of testing, should the remedy selection evaluation indicate remedy design studies are warranted.

The actual goal for removal efficiency must be based on site- and process-specific characteristics. The specified removal efficiency must meet site cleanup goals, which are based on a site risk assessment, or ARARs.

Example 2 illustrates the goal of a remedy selection treatability study at the Superfund site introduced in Example 1. In this example, the remedy selection treatability studies

Example 2. Remedy Selection

As followup to the jar test results discussed in Example 1, a series of bench tests were designed to more accurately determine the feasibility of using soil washing to reduce the volume of contaminated soil at the facility. The bench tests included a series of studies, each designed to measure a single variable while holding all others constant. The following treatment process variables were evaluated:

- Ratios of soil and wash water
- Washing/mixing/agitation time
- Wash water temperature
- Additives such as acids, surfactants, and chelating agents
- Rinse system cycles

In all, 24 different tests were completed and each test was performed in duplicate, as a measure of variance, for a total of 48 tests. Soils recovered on the sieves and from wash waters (filtered to remove very fine soil particles) were analyzed for the five metals of interest using standard EPA SW846 methods. The bench tests also evaluated the possibility of altering screen sizes to capture a larger segment of clean soil (particles >1 mm).

The bench test results for the >2 mm fraction showed that optimal results (as measured by total metal concentration reductions) were obtained under the following conditions:

- Soil to wash water ratio of 1:2
- Mixing/agitation time of 15 minutes
- Wash water temperature of at least 100°F
- Wash water pH of 4-5
- Single 60 second rinse of the screened soil using pressure sprayer

This set of process conditions was able to reduce the concentration of all metals in the recovered >2 mm fraction by at least 90 percent, and some by as much as 95 percent. Surfactants and chelating agents were found to be counterproductive. They fouled the screening operations, and were not recommended for further evaluation for this site. The tests also showed that similar results (85 to 90 percent effective reductions in metal concentrations) could be obtained for the 1 to 2 mm particle size soil fraction. By separating the washed soil into >1 mm and <1 mm size groups, over 50 percent of the original soil volume could be effectively treated. However, particles smaller than 1 mm were not effectively cleaned by the process. In fact, the <1 mm soil fraction carried higher concentrations of metals after sieving than the whole soil carried before treatment. Hence, most of the metal contamination in these site soils is associated with soil particles 1 mrn or less in diameter.

Results from the study were compared to the proposed risk-based soil cleanup goals for the site. Based on this comparison, the study showed that the proposed cleanup goals could be met for a least 50 percent of the soil volume through the applied use of soil washing technology.

show that site cleanup goals can be met. Soil washing is chosen as the selected remedy in the ROD.

4.2 EXPERIMENTAL DESIGN

4.2.1 Remedy Screening Tier

A jar test can be rapidly performed in an onsite laboratory to evaluate the potential performance of soil washing as an alternative technology. Jar tests are performed at the equivalent of Analytical Levels I and II, which correspond to field screening and field analysis, respectively.[11]

When assessing the need for jar tests, the investigator should use available knowledge of the site location and any preliminary analytical data on the type and concentration of contaminants present. Soil engineering properties are available from Soil Conservation Surveys. At this level of treatability study, the most significant soil property is particle size distribution. In survey documents, particle size distribution is categorized into five groupings: fragments or particles greater than 3 inches in diameter, and fragments passing through #4 (4.75 mm), #10 (2.0 mm), #40 (0.425 mm), and #200 (0.07 mm) sieves. Generally, soils with a 10 to 15 percent passing rate through a #200 mesh screen have proven ideal for soil washing. However, soil particle size is not the only property to consider. The collective effect of all soil and contaminant properties must be investigated. Even soil characterized by a 95 percent passage through a #200 screen may be a possible candidate for soil washing if the contaminant is water soluble or loosely bound to soil particles.

Contaminant characteristics to examine during remedy screening include solubility, miscibility, and dispersibility. Properties of organic contaminants are generally easier to evaluate than those of inorganic contaminants. Inorganics, such as heavy metals, can exist in many compounds (e.g., oxides, hydroxides, nitrates, phosphates, chlorides, sulfates, and other more complex mineralized forms), which can greatly alter their solubilities. Metal analyses typically provide only total metal concentrations. More detailed analyses to determine chemical speciation may be warranted.

The liquid used in the jar test is typically water, or water with additives that might enhance the effectiveness of the soil washing process. To save time and money, chemical analyses should not be performed on the samples until there is visual evidence that physical separation has taken place in the jar tests. Jar tests can yield three separate fractions from the original soil sample. These include a floating layer, a wastewater with dispersed solids, and a solid fraction. Chemical analysis can be performed on each fraction.

When performing the jar test, observe if any floating materials can be skimmed off the top. Observe whether an immiscible, oily layer forms, either at the top or the bottom, indicating release of an insoluble organic material. Observe and time the solids sealing rate and depth. Sand and gravel settle first, followed by the silt and clay. The rate and the relative volume of the settling material will provide some indication of the particle size distribution in the contaminated matrix and the potential for soil washing as a treatment alternative. Further evidence can be gained by analyzing the settled and filtered wash water for selected indicator contaminants of concern. If simple washing releases a large percentage of these contaminants into the wash water, then soil washing can be viewed favorably, and more detailed laboratory and bench tests must be conducted.

Variations on the jar tests can include the addition of surfactants, chelants, or other dispersant agents to the water; sequential washing; heated water washing versus cold water; acidic or basic wash water; and tests that include both a wash and a rinse step. The rinse water and fine soil fraction (<2 mm particle size) should be separated from the coarse soil fraction (>2 mm particle size) using a #10 sieve. No attempt should be made during jar tests to separate the soil into discrete size fractions; this is done at the remedy selection tier of testing as described in Section 4.2.2. Normally, only the coarse soil fraction should be analyzed for contamination. In general, at least a 50 percent reduction in total contaminant concentration in the >2 mm soil fraction is considered adequate to proceed to the remedy selection tier. The separation of approximately 50 percent of the total soil volume as clean soil also indicates remedy selection studies may be warranted.

To reduce analytical costs during the remedy screening tier, a condensed list of known contaminants must be selected as indicators of performance. The selection of indicator analytes to track during jar testing should be based on the following guidelines:

1) Select one or two contaminants present in the soil that are most toxic or most prevalent.

2) Select indicator compounds to represent other chemical groups if they are present in the soil (i.e., volatile and sentivolatile organics, chlorinated and nonchlorinated species, etc.)

3) If polychlorinated biphenyls (PCBs) and dioxins are known to be present, select PCBs as indicators in the jar tests and analyze for them in the washed soil. It is usually not cost-effective to analyze for dioxins and other highly insoluble chemicals in the wash water generated from jar tests. Check for them later in the wash water from remedy selection tests.

4.2.2 Remedy Selection Tier

This series of tests requires electricity, water, and additional equipment be available. The tests are run under more controlled conditions than the jar tests. The response of the soil sample to variable washing conditions is fully characterized. More precision is used in weighing, mixing, and particle size separation. There is an associated increase in quality assurance/quality control (QA/QC) costs. Treated soil particles are separated during the sieve operations to determine contaminant partitioning with particle size. Chemical analyses are performed on the sieved soil particles as well as on the spent wash waters. The impact of process variables on washing effectiveness is quantified. This series of tests is considerably more costly than jar tests, so only samples showing promise in the remedy screening phase (jar test) should be carried forward into the remedy selection tier. If sufficient data are available in the prescreening step, the remedy screening step may be skipped. Soil samples showing promise in the prescreening step are carried forward to the remedy selection tier. The objective of the remedy selection soil washing design is to meet the goals discussed in Section 4.1.2.

A series of tests should be designed that will provide information on washing and rinsing conditions best suited to the soil matrix under study. The RREL data base should be searched for information from previous studies. To establish percent of contaminant removal, particle size separation, and distribution of contaminants in the washed soil, the following should first be studied: 1) wash time, 2) wash water-to-soil ratio, and 3) rinse water-to-wash water ratio. Following those studies, the effect of wash water additives on performance should be evaluated.

Several factors must be considered in the design of soil washing treatability studies. A remedy selection test design should be geared to the type of system expected to be used in the field. Soil-to-wash water ratios should be planned using the results from the jar tests, if jar tests are performed. In general, a ratio of 1 part of soil to 3 parts of wash water will be sufficient to perform remedy selection tests. The soil and wash water should be mixed on a shaker table for a minimum of 10 minutes and a maximum of 30 minutes. The soil-to-wash water ratio and mix times presented here are rules of thumb to be used if no other information is available.

Another factor to consider is the variability of the grain size distribution. Gilsen Wet Sieve devices are recommended for remedy selection studies. Ro-Tap or similar sieve systems may also be used. Such devices will enhance the completeness and reproducibility of grain size separation. However, they are messy, expensive, and very noisy when in operation. An alternate choice is to complete a series of four to six replicate runs under exactly the same set of conditions to obtain information on the variability of the grain size separation technique. Variability in the separation technique can be evaluated by comparing sieve screen weights across runs and soil contaminant data for the same fractions from each run. By identifying the range of variability associated with repeated runs at the same conditions, estimates can be made of the variability that is likely to be associated with other test runs under slightly different conditions.

Normally, only the wash water and the soil particles captured by the sieve screen need to be analyzed for contaminants. Experience has shown that little additional contaminant removal is likely to be found in the rinse water. Rinsing is important and must be included in the procedure since it improves the efficiency of the grain size separation/sieving process. Rinsing separates the fine from the coarse material. This can result in a cleaner coarse fraction and more contaminant concentrated in the fine fraction. Contaminant concentration in the rinse water may be determined periodically (e.g., 10 percent of the samples) to evaluate the performance of the wash solution. However, very little contamination is typically dissolved in the rinse solution. Therefore, analyses of the rinse solution may have limited value in verifying wash solution performance.

Initially, only the coarse soil fraction and the wash water should be analyzed for indicator contaminants. If the removal of the indicator contaminants confirms that the technology has the potential to meet cleanup standards at the site, additional analyses should be performed. All three soil fractions and all wash and rinse waters must be analyzed for all contaminants to perform a complete mass balance. The holding time of soil fractions in the lab before extraction and analysis can be an important consideration for some contaminants.

The decision on whether to perform remedy selection testing on hot spots or composite soil samples is difficult and must be made on a site-by-site basis. Hot spot areas should be factored into the test plan if they represent a significant portion of the waste site. However, it is more practical to test the specific waste matrix that will be fed to the full-scale system over the bulk of its operating life. If the character of the soil changes radically (e.g., from clay to sand) over the depth of contamination, then tests should be designed to separately study system performance on each soil type, Additional guidance on soil sampling techniques and theory can be found in Soil Sampling Quality Assurance User's Guide.[21] and Methods for Evaluating the Attainment of Cleanup Standards.[18]

Additives such as oil and grease dispersants and chelating agents can aid in removing contaminants from some soils. However, they can also cause processing problems downstream from the washing step. Therefore, use of such additives should be approached with caution. Use of one or a combination of those additives is a site-by-site determination, Some soils do not respond well to additives. Surfactants and chelating agents may form suspensions and foams with soil particles during washing. This can clog the sieves and lead to inefficient particle size separation during screening. The result can be the recovery of soil fractions with higher contamination than those cleaned by water alone. Such results can make the data impossible to understand. Additives can also complicate the rinse water process that might follow the soil washing. Recent studies have shown that counter-current washing-rinsing systems, incorporating the use of hot water for the initial wash step, offer the best performance in terms of particle size separation, contaminant removal, and wastewater management (treatment, recycling and discharge). Additional details regarding the performance of surfactants and chelating agents in reducing lead contamination in soils from battery recycling Superfund sites can be found in Lead Battery Site Treatability Studies, Project Summary[16]

4.3 EQUIPMENT AND MATERIALS

The Work Plan should specify the equipment and materials needed for the treatability test. For example, the size and type of glassware or containers to be used during the test should be specified. Standard laboratory methods normally dictate the types of sampling containers that can be used with various contaminant groups. The RPM should consult such methods for the appropriate containers to be used for the treatability studies,[23] Normally, glass containers should be used. Stainless steel can also be used with most contaminants. Care should be taken when using various plastic containers and fittings. Such materials will absorb many contaminants and can also leach plasticizer chemicals, such as phthalates, into the soil matrix. Appropriate methods for preserving samples and specified holding times for those samples should be used.

The following equipment is recommended for remedy selection soil washing tests:

Basic Equipment

- Reciprocating shaker table
- Four to six 10-liter glass jars and lids
- pH meter
- Electric hot plate/magnetic stir mixer
- Top-loading balance
- Four 2-liter graduated cylinders
- Timer
- Stainless steel sieve screens (#10 and #60) - two sets
- Four collection pans/buckets for rinse and wash water collection
- Sample jars
- Scoops (disposable)
- Spray device for rinsing (stainless steel garden sprayers work well)
- Filter and media
- Vacuum pump

Optional Equipment

- Ro-Tap
- Gilsen Wet Sieve

4.4 SAMPLING AND ANALYSIS

The Work Plan should describe the procedures to be used in field and treatability study sampling. The procedures to be used will be site-specific.

4.4.1 Field Sampling

A sampling plan should be developed that directs the collection of representative soil samples from the site for the treatability test. The sampling plan is site-specific. It describes the number, location, and volume of samples. Heterogeneous soils, variations in the contaminant concentration profile, and different contaminants in different locations in the site will complicate sampling efforts. If the objective of the remedy screening or remedy selection treatability tier study is to investigate the performance of soil washing at the highest contaminant concentration, the sample collection must be conducted at a "hot spot." This will require conducting a preliminary site sampling program to identify the locations of highest contaminant concentration. (This information is generated early in the RI process.) If the soil and types of contaminants vary throughout the site, extensive sampling may be required. If soil washing is being considered only for certain areas of the site, the sampling program may be simplified by concentrating on those areas.

If the objective of the remedy selection study is to investigate the use of the technology for a more homogenous waste, an "average" sample for the entire site must be obtained. This will require a statistically based program of mapping the site and selecting sampling locations that represent the variety of waste characteristics and contaminant concentrations present. The selection of soil sampling locations should be based on knowledge of the site. Information from previous soil samples, soil gas analysis using field instrumentation, and obvious odors or residues are examples of information that can be used to specify sample locations.

Chapter 9 of Test Methods for Evaluating Solid Waste[23] presents a detailed discussion of representative samples and statistical sampling methods. Additional sources of information on field sampling procedures can be found in the Annual Book of ASTM Standards,[1] and NIOSH Manual of Analytical Methods (February 1984).[9] The EPA publications Soil Sampling Quality Assurance User's Guide[21] and Methods for Evaluating the Attainment of Cleanup Standards[18] should be consulted to plan effective sampling programs for either simple or complex sites.

The method of sample collection is site-specific. For example, drill rigs or hand augers can be used to collect samples, depending on the depth of the sample required and the soil characteristics. If the target contaminants are volatile and the samples are composited, care should be taken to minimize the loss of volatile compounds. Compositing samples on ice is a good method for minimizing the loss of volatile compounds. Compositing is usually appropriate for soils containing nonvolatile constituents.

4.4.2 Waste Analysis

Section 2.2.3 detailed the physical tests that are useful in characterizing the soil matrix at the site during the prescreening step. The key for successful soil washing treatability studies is to properly select the soil feedstock (e.g., sand, loam, clay, etc.) based on the initial prescreening and additional soil characterizations. Other important soil characteristics include the pH and moisture content of the soil. The pH is important in determining the compatibility of soil washing fluids. The speciation of metal compounds may also be affected by soil pH. The soil moisture content is an important consideration for materials handling.

Standard analyses for contaminants at Superfund sites should identify the contaminants of concern. It is important to determine the solubility and volatility of organics. Contaminant solubility will give an indication of whether washing solution additives will be required. Volatility will be an important consideration for materials handling. If high concentrations of volatiles are present, pretreatment (e.g., using soil vapor extraction) or collection and treatment of air emissions may be required. Metal speciation will be an important consideration in determining metal solubility.

The spatial distribution and variations in the concentrations of contaminants will be important for the design of treatability studies. Complex mixtures of contaminants may be difficult to treat economically. A number of wash stages and additives may be required to successfully remove many contaminants. The cost of such a system may be prohibitive. Frequent changes in contaminant composition can cause dramatic changes in removal efficiencies.

4.4.3 Process Control Sampling and Analysis

This is not applicable to remedy screening and remedy selection.

4.4.4 Treatment Product Sampling and Analysis

Soil washing is not a stand-alone process (see Section 2.1. 1). It generates residuals that must be treated further and disposed of properly. Because the nature of soil washing equipment and procedures varies greatly between manufacturers, remedy design testing is necessary to evaluate the type, quantity, and properties of residuals.

Analyze the washed soil and each of the various wastestreams (wash water, fine sediment, etc.) for the contaminants identified in the original soil analyses. In many cases, indicator contaminants, which are representative of a larger group of contaminants, can be analyzed in place of a full scan. Caution must be exercised in using indicator contaminants since soil washing efficiencies can vary from one contaminant to another. The process efficiency may be either understated or overstated when analyzing for indicator compounds.

If several soil washing studies are run to test the effects of operating parameters on washing efficiency (i.e., the addition of surfactants, chelating agents, etc.), samples should be taken of each test before and after soil washing. Typically, these tests are run in triplicate.

4.4.5 Sampling and Analysis Plan (SAP) and Quality Assurance Project Plan (QAPjP)

A SAP is required for all field activities conducted during the RI/FS. The SAP consists of the Field Sampling Plan and the QAFjP. This section of the Work Plan describes how the RI/FS SAP is modified to address field sampling, waste characterization, and sampling activities supporting treatability studies. It describes the samples to be collected and specifies the level of QA/QC required. See Section 5 for additional information on the SAP.

4.5 DATA ANALYSIS AND INTERPRETATION

The Work Plan should discuss the techniques to be used in analyzing and interpreting the data. The objective of data analysis and interpretation is to provide sufficient information to the RPM and EPA management to assess the feasibility of soil washing as an alternative technology. After remedy selection testing is complete, the decision must be made whether to proceed to the remedy design testing tier, to a full-scale soil washing remediation, or to rule out soil washing as an alternative. The data analysis and interpretation are a critical part of the remedy selection process.

Methods commonly used to analyze and interpret data generated in the soil washing process, such as particle size distribution of the soil, chemical analysis of the contaminants present, and test process variables, apply to all three tiers of the soil washing treatability study.

The particle size distribution of the soil is a standard physical characterization technique. Recent studies indicate that contamination is often distributed as a function of soil particle size. Treatment efficiency is a function of particle size as well. Three particle size ranges have been frequently studied: >2 mm, 0.25 to 2 mm, and <0.25 mm. These fractions are obtained from U.S. Standard Sieve Series #10 and #60. Figure 4-1 shows the applicable particle size ranges plotted against the sieve throughput percent by weight.[12.]

Range I consists of coarse soils. Soils in Range I are economically washed with simple particle size separation when contaminants are concentrated in the smaller particles. When fractionation does not occur, as is the case

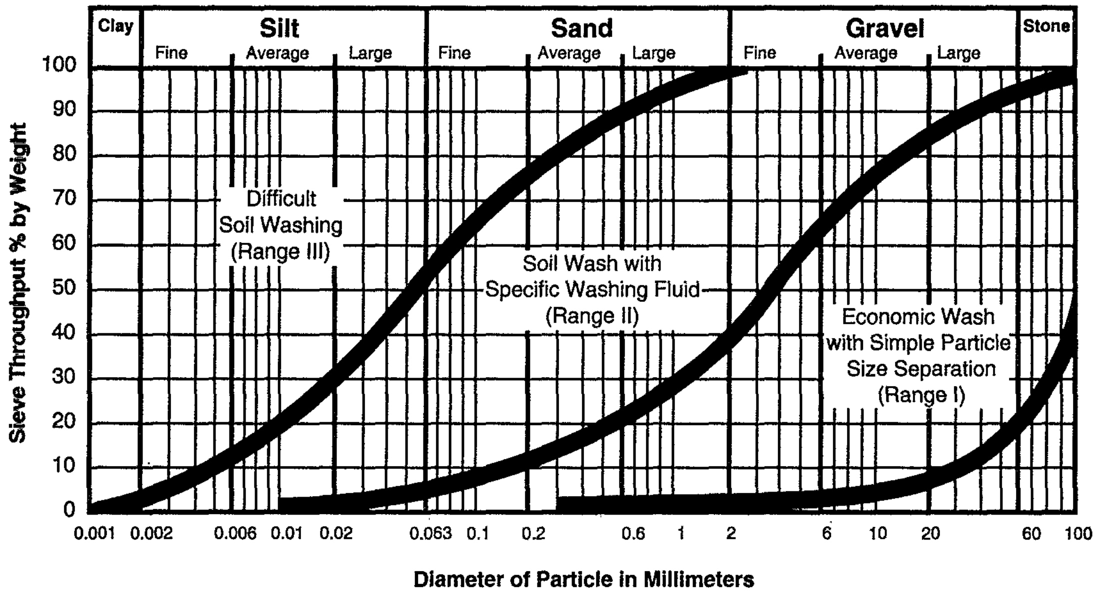


FIGURE 4-1. Soil washing applicable particle size range.

with lead, there is no improvement in the economics of separation when the soil is in Range I.

Soils in the area to the right of Range I are primarily stone and large gravel. Particle size separation is normally not feasible for these materials due to their, large size. However, soluble contaminants may be removed from such soils in the wash water.

Most contaminated soils lie in Range II. The types of contaminants present govern. the composition of wash fluids and affect the overall process efficiency. Process efficiency is also affected by soil particle distribution patterns and the fractionation of contaminants in fine particles. Both particle size separation and contaminant solubilization can be important for cost-effective treatment of soils in Range II.

Soils in Range III consist primarily of fine sand, silt, and clay. Frequently, such soils have high humic content and organics may be strongly adsorbed. Particle size separation may be effective in concentrating contaminants adsorbed to particles in this size range into a smaller volume.[12]

Figure 4-2 is a hypothetical contaminant distribution histogram for soil. The histogram represents results of chemical analyses on contaminated bulk and fractionated soil

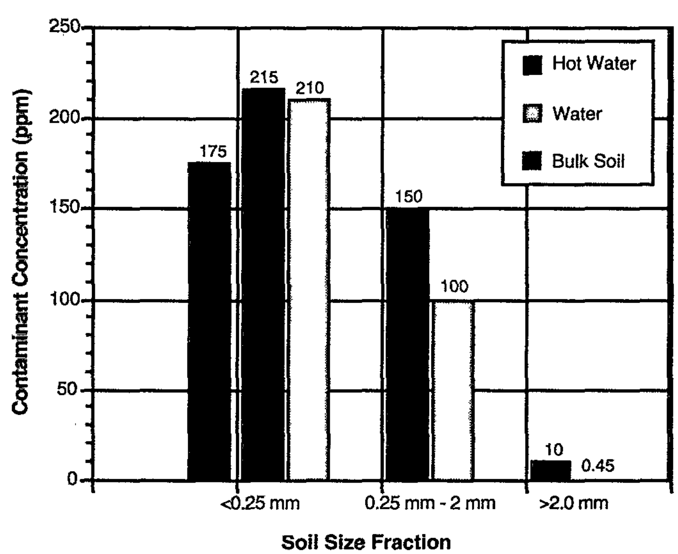


FIGURE 4-2. Hypothetical contaminant distribution by soil fraction before and after treatment.

before and after two treatments. The soil was treated with water at ambient temperature and hot water. The data show that contaminant is concentrated in the <2 mm soil fractions. Water at ambient temperature was able to reduce the contamination in the >2 mm fraction to 10 parts per million (ppm) (a contaminant reduction of approximately 94 percent). Hot water improved the performance by reducing the contaminant concentration to 0.45 ppm in the >2 min fraction (a contaminant reduction of over 99 percent). Contaminant concentrations in the other fractions (0.25 to 2 mm and <0.25 nun) were not appreciably affected by soil washing.

Figure 4-3 shows a plot of agitated contact time against contaminant removal efficiency and final contaminant concentration in the >2 mm soil fraction. The contaminant concentration in each soil fraction would normally be plotted at each time point. In this graph, the initial concentration is 500 ppm and the contaminant cleanup goal is 200 ppm. It is apparent that the agitated contact time must be a minimum of 14 minutes to provide contaminant removal efficiencies that meet the cleanup goals. The effectiveness of treatment can be expressed as a percent reduction of contaminant. In this case, there is a 60 percent reduction in contaminant concentration in the >2 mm soil fraction at 14 minutes. The figure also demonstrates that, for the soil studied, mixing times of greater than 14 to 15 minutes result in diminishing returns. The shape of this curve will be different for each soil.

An objective of the remedy selection soil washing treatability testing is to determine how the treatment is affected by the process design variables. These variables may include soil-to-wash water ratio, type of mechanical agitation used, agitated contact time, rinse-water-to-wash water volume ratio, wash water temperature, system pH, and wash water additives. Often, two or more of these variables may affect the results. Statistical analysis of the data can be performed using standard techniques to differentiate sources of change and interactions between these sources. For a detailed discussion of the ANOVA techniques, refer to the document entitled Statistical Analysis of Groundwater Data at RCRA Facilities (Interim Final)[20] and Brookes, et al.[5]

4.6 REPORTS

The last step of the treatability study is reporting the results. The Work Plan discusses the organization and content of interim and final reports. Complete, accurate reporting is critical because decisions about implementability will be partly based on the outcome of the study. The RPM may not require formal reports at each soil washing study tier. Interim reports should be prepared after each tier. Project briefings should be made to interested parties to determine the need for and scope of the next tier of testing. To facilitate the reporting of results and comparisons between treatment alternatives, a sug-

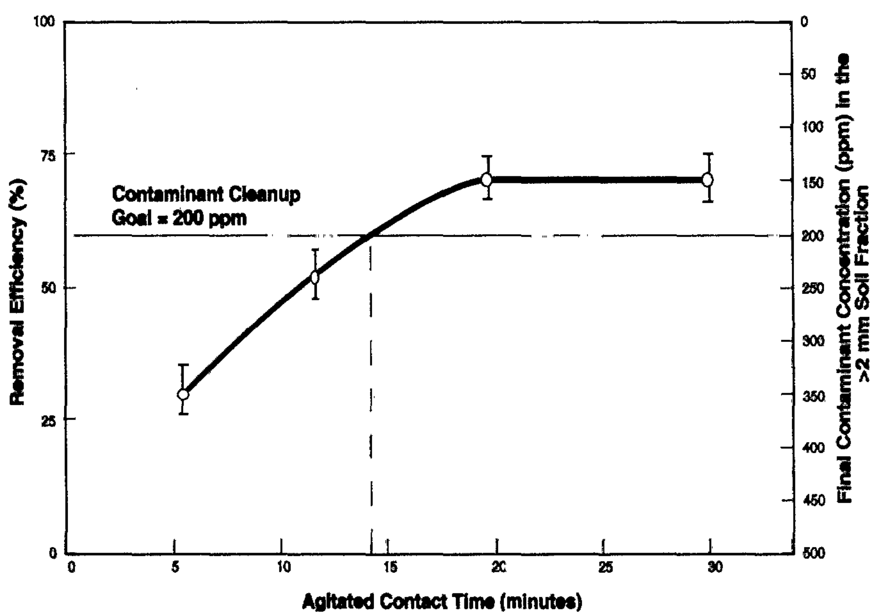
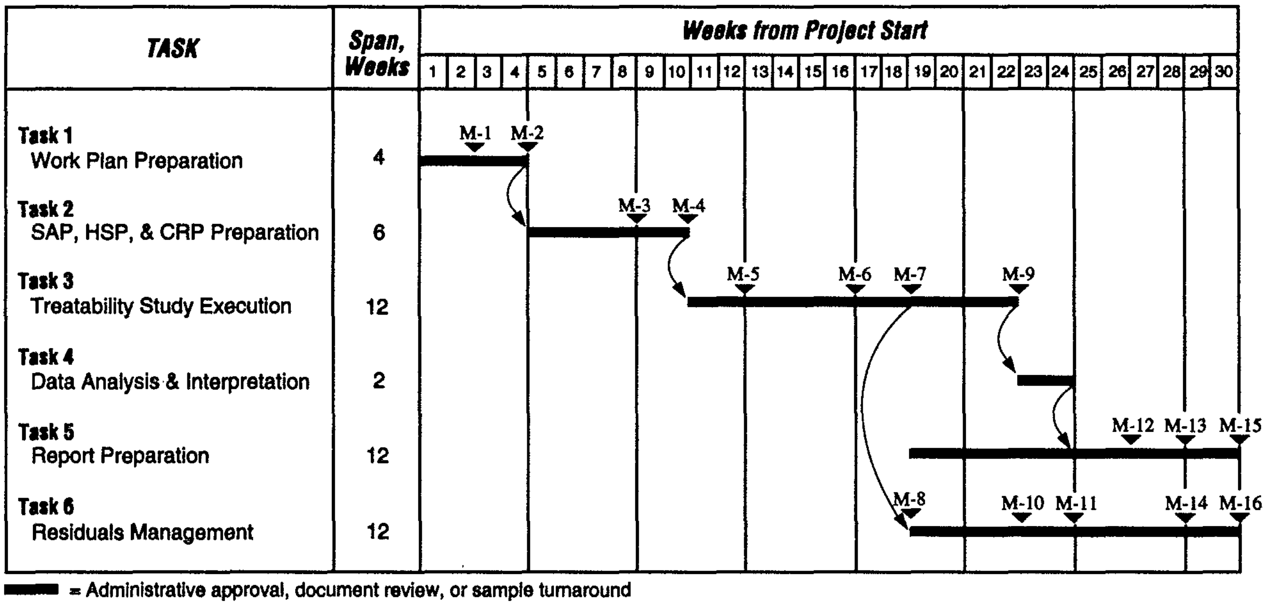


FIGURE 4-3. Plot of agitated contact time versus contaminant removal efficiency and final contaminant concentration in the >2 mm soil fraction.



M-1	Submit Work Plan	Wk 2	M-9	Receive Treatability Study Analytical Results	Wk 22
M-2	Receive Work Plan Approval	Wk 4	M-10	Receive Project Residual Analytical Results	Wk 22
M-3	Submit SAP, HSP, CRP	Wk 8	M-11	Submit Waste Disposal Approval Form	Wk 24
M-4	Receive SAP, HSP Approvals	Wk 10	M-12	Submit Draft Report	Wk 26
M-5	Collect Sample	Wk 12	M-13	Receive Review Comments	Wk 28
M-6	Receive Sample Characterization Results	Wk 16	M-14	Receive Waste Disposal Approval	Wk 28
M-7	Collect Treatability Study Samples	Wk 18	M-15	Submit Final Report; Conduct Briefing	Wk 30
M-8	Collect Project Residual Samples	Wk 18	M-16	Ship Wastes to TSDF	Wk 30

FIGURE 4-4. Example project schedule for a treatability study.

gested table of contents is presented in the generic guide.[15] At the completion of the study, a formal report is always required.

OERR requires that a copy of all treatability study reports be submitted to the Agency's Superfund Treatability Data Base repository. One copy of each treatability study report must be sent to:

U.S. Environmental Protection Agency
Superfund Treatability Data Base
ORD/RREL
26 West Martin Luther King Dr.
Cincinnati, Ohio 45268

4.7 SCHEDULE

The Work Plan includes a schedule for completing the treatability study. The schedule gives the anticipated starting date and ending date for each of the tasks described in the Work Plan and shows how the various tasks interface.

The time span for each task accounts for the time required to obtain the Work Plan, subcontractor, and other approvals (e.g., disposal approval from a commercial TSDF); sample curing time, if necessary; analytical turnaround time; and review and comment period for reports and other project deliverables. Some slack time also should be built into the schedule to accommodate unexpected delays (e.g., bad weather, equipment downtime) without affecting the project completion date.

The schedule is usually displayed in the form of a bar chart (Figure 4-4). If the study involves multiple tiers of testing, all tiers should be shown on one schedule. Careful planning before the start of the tests is essential. Depending on the review and approval process, planning can take up to several months. Barring any difficulties, such as acquiring sampling equipment and site access, the field work phase can generally be accomplished in two weeks. Setup of the laboratory and procurement of necessary equipment and lab supplies for treatability studies may take a month. Analytical results can be available in less than 30 days, depending on how rapidly laboratory results can be pro-

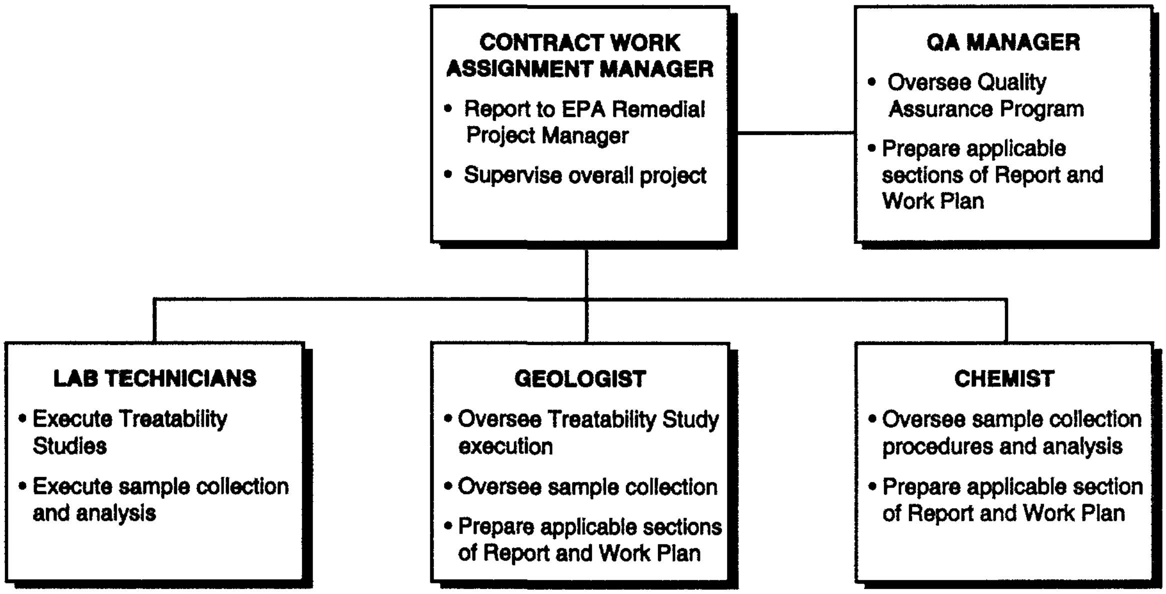


FIGURE 4-5. Organization chart.

vided. Shorter analytical turnaround time can be requested but this will normally double the costs. Compounds such as pesticides and PCBs may require longer turnaround times due to the extractions and analyses involved. Depending on the objectives,, the duration of treatability tests may be longer.

Interpretation of the results and final report writing may take 1 to 2 months, but this is highly dependent on the review process. Remedy screening tests typically take from a few hours to several days. It is not unusual for the remedy selection soil washing treatability test to be a 2 to 3 month project.

4.8 MANAGEMENT AND STAFFING

The Work Plan discusses the management and staffing of the remedy selection treatability study. The Work Plan specifically identifies the personnel responsible for executing the treatability study by name and qualifacations. Generally, the following expertise is needed for the successful completion of the treatability study:

- Project Manager (Work Assignment Manager)
- Chemist
- Geologist
- Lab Technician

Responsibility for various aspects of the project is typically shown in an organizational chart such as the one in Figure 4.5

4.9 BUDGET

The Work Plan discusses the budget for completion of the remedy selection treatability study. Testing costs for remedy selection depend on a variety of factors. Table 4-2 provides a list of potential major cost estimate components this tier. For most tests, the largest single expense is the analytical program.

TABLE 4-2.Major Cost Elements Associated with Remedy Selection Soil Washing Studies

Cost Element	Cost Range (1,000s of dollars)
Initial Data Review	1 - 10
Work Plan Preparation	1 - 5
Field Sample Collection	1 - 10
Field Sample Chemical Analysis	5 - 25
Laboratory Setup/Materials	5 - 25
Treatability Test Chemical Analysis	5 - 20
Data Presentation/Report	2 - 5
TOTAL COST RANGE	20 -100

Sites where the soil types, contaminant types, and contaminant concentration vary widely will usually require more samples than sites where the soil and contamination is more homogeneous. It is not unusual for the sampling, analysis, and QA activities to represent 50 percent of the total testing cost. In general, the costs for analyzing organics are more expensive than for metals. Actual costs will vary according to individual laboratories, required turnaround times, volume discounts, and any customized testing. Sampling costs will be influenced by the contaminant types and depth of contamination found in the sod. The health and safety considerations during sampling activities are more extensive when certain contaminants (e.g., volatile organics) are present in the soil. Level B personal protective equipment (PPE) rather than Level D PPE can increase the cost component an order of magnitude. Sampling equipment for surface samples is much less complicated than equipment used for depth samples. Depending on the number of samples and tests specified, residuals management (e.g., contaminated soil fraction and wash waters) will require proper treatment and/or disposal. Treatment and disposal of the residuals as hazardous wastes increases costs significantly.

Other factors to consider include report preparation and the availability of vital equipment and laboratory supplies. Generally, an initial draft of the report undergoes internal review prior to the final draft. Depending on the process, final report preparation can be time consuming as well as costly. Procurement of testing equipment (e.g., reciprocating shaker table) and laboratory supplies (e.g., reagents and glassware) will also increase the costs.

Typical costs for remedy selection tests are estimated to be from $20,000 to $100,000. Remedy screening, with its associated lack of replication and detailed testing, ranges from 25 to 50 percent of these costs. These estimates are highly dependent on the factors discussed above. Not included in these costs are the costs of governmental procurement procedures, including soliciting for bids, awarding contracts, etc.

SECTION 5
SAMPLING AND ANALYSIS PLAN

The Sampling and Analysis Plan (SAP) consists of two parts–the Field Sampling Plan (FSP) and the Quality Assurance Project Plan (QAPjP). The purpose of this section is to identify the contents and aid in the preparation of these plans. The RI/FS requires a SAP for all field activities. The SAP ensures that samples obtained for characterization and testing are representative and that the quality of the analytical data generated is known and appropriate. The SAP addresses field sampling, waste characterization, and sampling and analysis of the treated wastes and residuals from the testing apparatus or treatment unit. The SAP is usually prepared after Work Plan approval.

5.1 FIELD SAMPLING PLAN

The FSP component of the SAP describes the sampling objectives; the type, location and number of samples to be collected; the sample numbering system; the equipment and procedures for collecting the samples; the sample chain-of-custody procedures; and the required packaging, labeling, and shipping procedures.

The sampling objectives must be consistent with the treatability test objectives. The primary objective of remedy selection treatability studies is to evaluate the extent to which specific chemicals are removed from the soil. The primary sampling objectives include:

- Acquisition of samples representative of conditions typical of the entire site or defined areas within the site. Because a mass balance is required for this evaluation, statistically designed field sampling plans may be required. However, professional judgment regarding the sampling locations may be exercised to select sampling sites that are typical of the area (pit, lagoon, etc.) or appear above the average concentration of contaminants in the area being considered for the treatability test. Selection may be difficult because reliable site characterization data may not be available early in the remedial investigation.
- Acquisition of sufficient sample volumes necessary for testing, analysis, and quality assurance and quality control (QA/QC).

From these two primary objectives, more specific objectives are developed. When developing the more detailed objectives, consider the following types of questions:

- Will samples be composited to provide more representative samples for the treatability test, or will the potential loss of target volatile organic compounds prohibit this sample collection technique?
- Is there adequate data to determine sampling locations indicative of the more contaminated areas of the site? Contaminants may be widespread or isolated in small areas (hot spots). Contaminants may be mixed with other contaminants in one location and appear alone in others. Concentration profiles may vary significantly with depth.
- Are the soils homogeneous or heterogeneous? Soil types can vary across a site and will vary with depth. Changes in soil composition can reduce the effectiveness of soil washing.
- Is sampling of a “worst-case” scenario warranted? The decision on whether to perform remedy selection testing on specific areas or composite samples is difficult and must be made on a site-by-site basis. Hot spots and areas with soils that may be difficult to treat should be factored into the test plan if they represent a significant portion of the waste site.

After identifying the sampling objectives, an appropriate sampling strategy is described. Specific items that should be briefly discussed in the FSP and QAPjP are listed in Table 5-1.

Table 5-1 presents the suggested organization of the Sampling and Analysis Plan.

TABLE 5-1. Suggested Organization of Sampling and Analysis Plan

Field Sampling Plan

1. Site Background
2. Sampling Objectives
3. Sample Location and Frequency
   – Selection
   – Media Type
   – Sampling Strategy
   – Location Map
4. Sample Designation
   – Recording Procedures
5. Sample Equipment and Procedures
   – Equipment
   – Calibration
   – Sampling Procedures
6. Sample Handling and Analysis
   – Preservation and Holding Times
   – Chain-of-Custody
   – Transportation

Quality Assurance Project Plan

1. Project Description
   – Test Goals
   – Critical Variables
   – Test Matrix
2. Project Organization and Responsibilities
3. QA Objectives
   – Precision, Accuracy, Completeness
   – Representativeness and Comparability
   – Method Detection Limits
4. Sampling Procedures
5. Sample Custody
6. Calibration Procedures and Frequency
7. Analytical Procedures
8. Data Reduction, Validation, and Reporting
9. Internal QC Checks
10. Performance and System Audits
11. Preventive Maintenance
12. Calculation of Data Quality Indicators
13. Corrective Action
14. QC Reports to Management
15. References
16. Other Items

5.2 QUALITY ASSURANCE PROJECT PLAN

5.2.1 Experimental Design

Section 1 of the QAPjP must include an experimental project description that clearly defines the experimental design, the experimental sequence of events, each type of critical measurement to be made, each type of matrix (experimental setup) to be sampled, and each type of system to be monitored. This section may reference Section 4 of the Work Plan. All details of the experimental design not finalized in the Work Plan should be defined in this section.

Items to be included, but not limited to, are:

- Number of samples (area) to be studied
- Identification of treatment conditions (variables) to be studied for each sample (i.e., wash time, wash water-to-soil ratio, rinse water-to-wash water ratio, and additives to be evaluated)
- Soil size fractions
- Target compounds for each sample
- Number of replicates per treatment condition

The Project Description clearly defines and distinguishes the critical measurements and observations made and system conditions (e.g., process controls, operating parameters, etc.) routinely monitored. Critical measurements are those measurements, data gathering, or data generating activities that directly affect the technical objectives of a project. At a minimum, the determination of the target compound (identified above) in the untreated and treated soil samples and the particle size distribution of the untreated soil will be critical measurements.

The purpose of the remedy selection treatability study is to determine whether soil washing can meet cleanup goals and provide information to support the detailed analysis of alternatives (i.e., seven of the nine evaluation criteria). An example of a criterion for this determination is a removal of approximately 90 percent of the contaminants. The exact removal efficiency specified as the goal for the remedy selection test is site specific.

5.2.2 Quality Assurance Objectives

Section 2 lists the QA objectives for each critical measurement and sample matrix defined in Section 1. These objectives are presented in terms of the six data quality indicators: precision, accuracy, completeness, representativeness, comparability, and, where applicable, method detection limit.

5.2.3 Sampling Procedures

The procedure used to obtain field samples for the treatability study is described in the FSP. They need not be repeated in this section, but should be incorporated by reference.

Section 3 of the QAPjP contains a description of a credible plan for subsampling the material delivered to the laboratory or the treatability study. The methods for aliquoting the residual material in each size fraction for different analytical methods must be described.

5.2.4 Analytical Procedures and Calibration

Section 4 describes or references appropriate analytical methods and standard operating procedures for the analytical method for each critical measurement made. In addition, the calibration procedures and frequency of calibration are discussed or referenced for each analytical system, instrument, device, or technique for each critical measurement.

The methods for analyzing the treatability study samples are the same as those for chemical characterization of field samples. Preference is given to methods in "Test Methods for Evaluating Solid Waste, SW-846, 3rd. Ed., November 1986.[23] Other standard methods may be used, as appropriate.[17] Methods other than gas chromatography/mass spectra (GC/MS) techniques are recommended to conserve costs when possible.

The purpose of the remedy selection treatability study is to detennine whether soil washing can meet cleanup goals and provide information to support the detailed analysis of alternatives (i.e., seven of the nine evaluation criteria). An example of a criterion for this determination is a removal of approximately 90 percent of contaminants. The exact removal efficiency specified as the goal for the remedy selection test is site-specific. The suggested QC approach will consist of:

- Triplicate samples of both reactor and controls
- The analysis of surrogate spike compounds
- The extraction and analysis of method blanks
- The analysis of a matrix spike in approximately 10 percent of the samples.

The analysis of triplicate samples provides for the overall precision measurements that are necessary to determine whether the difference is significant at the chosen confidence level. The analysis of the surrogate spike will determine if the analytical method performance is consistent (relatively accurate). The method blank will show if laboratory contamination has had an impact on the analytical results.

Selection of appropriate surrogate compounds will depend on the target compounds identified in the soil and the analytical methods selected for the analysis.

5.2.5 Data Reduction, Validation and Reporting

Section 5 includes, for each critical measurement and each sample matrix, a specific presentation of the following items:

- The data reduction planned for the collected data
- All equations used to calculate the final resultant value(s) from the raw critical measurement data, all unit conversions required and definitions of all terms, as well as the procedures for correcting analytical recovery
- The procedures used to validate data during data collection, transfer, storage, recovery, processing, and reporting steps
- The methods used to identify and treat outliers (i.e., data that fall outside the specified QA objective windows for method precision and accuracy)
- The data reporting scheme, including the flow from raw data through transfer, storage, recovery, processing, and validation; a flowchart is usually needed
- Identification of the specific individuals responsible for data handling at each step in the reporting scheme.

5.2.6 Internal Quality Control Checks

Section 6 describes and references each specific internal QC method followed, and indicates the frequency of use. (The term *internal* refers to both soil washing tests and laboratory activities, and applies to all organizations and individuals involved in the project.) Examples of the types of QC checks include the following:

- Split samples
- Replicate samples
- Replicate check standards
- Matrix-spiked samples

- Matrix-spiked replicates
- Laboratory pure water spikes (e.g., QC check samples)
- Surrogate spike compounds
- Internal standards
- Blanks (method, reagent, and/or instrument)
- Control charts (e.g., for calibration acceptance limits)
- Calibration standards and devices (traceable)
- Reagent checks (for all sample preparation and analysis methods involving the use of laboratory reagents)
- In-house proficiency testing prograrn to determine analyst's capabilities (including documented procedures).

5.2.7 Performance and Systems Audits

Section 7 describes the internal performance evaluation and technical system audits planned to monitor the capability and performance of the systems for obtaining critical measurement data.

At a minimum, a person independent of the analysis submits a quality control sample for all or some of the target compounds to the analytical laboratory. The results of the extraction and analysis document the capabilities of the personnel with the prescribed procedures.

5.2.8 Calculation of Data Quality Indicators

Section 8 describes the specific procedures that assess, on a routine basis, the precision, accuracy, completeness, and method detection limit (MDL) characteristic of each critical measurement for each sample matrix. Specifically, the following items are included:

- A brief description of each test procedure for each data quality indicator, measurement, and sample type
- Identification of the specific QC data used in each test procedure
- A brief discussion defining the statistical or mathematical methods used
- Specific equations used to calculate each data quality indicator, including definitions of reporting units of each term in the equations
- A statement of the frequency of each type of test.

5.2.9 Corrective Action

Section 9 describes the criteria and procedures by which initial corrective actions are implemented. These descriptions include the following elements:

- The predetermined limits for data acceptability; data outside these limits require corrective action
- The procedures for corrective action, from initial recognition of the condition requiring corrective action, through reporting of the condition, approval of the appropriate corrective action to be taken, implementation, and reporting of the results
- Identification of the individuals responsible for initiating, approving, implementing, and reporting the effectiveness of corrective actions.

5.2.10 Quality Control Reports

Section 10 describes the QA/QC information that will be included in the final project report. As a minimum, reports include:

- Changes to the QA Project Plan, if any
- Limitations or constraints on the applicability of the data, if any
- The status of QA/QC programs, accomplishments and corrective actions
- Results of technical systems and performance evaluation QC audits
- Assessments of data quality in terms of precision, accuracy, completeness, method detection limit, representativeness, and comparability.

The final report contains all the QA/QC information to support the credibility of the data and the validity of the conclusions. This information may be presented in an appendix to the report. Additional information on data quality objectives(11), quality assurance programs(13), and preparation of QAPjPs(19) is available in EPA guidance documents.

SECTION 6
TREATABILITY DATA INTERPRETATION

Proper evaluation of the potential of soil washing for remediating a site must compare the test results (described in Section 4.5) to the test objectives (described in Section 4.1) for each tier. The evaluation is interpreted in relation to seven of the nine RI/FS evaluation criteria, as appropriate. The remedy screening tier establishes the general applicability of the technology. The remedy design tier provides information in support of the evaluation criteria. The test objectives are based on established cleanup goals or other performance-based specifications (such as waste volume reduction). Soil washing testing must consider the technology as part of a treatment train.

Section 4.6 of this guide discusses the need for the preparation of interim and final reports and provides a suggested format. In addition to the raw and summary data for the treatability study and associated QC, the treatability report should describe what the results mean and how to use them in the feasibility study in screening/selecting alternatives. The report must evaluate the performance of the technology and give an estimate of the costs of further treatability studies and final remediation with the technology.

6.1 TECHNOLOGY EVALUATION

Remedy screening treatability studies typically consist of simple jar tests. The contaminant concentration in the soil before washing is compared to the contaminant concentration in the coarse soil fraction after washing. A reduction of approximately 50 percent of the soil contaminants during the test indicates additional treatability studies are warranted. Contaminant concentrations can also be determined for wash water and fine soil fractions. These additional analyses add to the cost of the treatability test and may not be needed. Before and after concentrations can normally be based on duplicate samples at each time period. The mean values are compared to assess the success of the study. A number of statistical texts are available if more information is needed.[4][7]

Jar tests can frequently be skipped when information about the soil type and contaminant solubilities is sufficient to decide whether remedy selection studies will be useful. An example of a prescreening evaluation and decision to bypass ajar test is provided in Example 3.

Example 3

A site in New Jersey has been used for the manufacture and storage of arsenic-containing pesticides. Soils at the site are contaminated with arsenic at levels ranging from 10 to 1,500 mg/ kg. The arsenic contamination is limited to the top 3 feet of soil. Sieve testing has shown that the upper 3 feet of soil contains 75 percent coarse sand and gravel (75 percent >2 mm diameter particles) by weight. Risk assessment studies conducted during the RI suggest that a cleanup goal of 100 mg/kg arsenic in onsite soils would be acceptable.

Previous studies indicated that many contaminants tend to be adsorbed on fine soil particles. Given this scenario, one can predict that there is at least a moderate chance that soil washing will be effective. It is entirely possible that the process will be able to reduce the arsenic content in 75 percent of the soil to 100 mg/kg or less. In this case, screening tests may be skipped in favor of conducting remedy selection tests that would determine optimal soil washing conditions (pH, additives, temperature, mixing/contact time, wastewater treatment) and performance at bench scale.

Sections 4.1 and 4.2 of this guide discuss the goals and design of remedy selection treatability studies, respectively. Typically, soil contaminant concentrations before soil washing and contaminant concentrations in the coarse fraction after soil washing are measured in triplicate. A reduction of approximately 90 percent in the mean concentration indicates soil washing is potentially useful in site remediation. A number of other factors must be evaluated before deciding to proceed to remedy design studies.

The final concentrations of contaminants in the recovered (clean) soil fraction, in the fine soil fraction and wastewater treatment sludge, and in the wash water are important to evaluating the feasibility of soil washing. The selection of technologies to treat the fine soil and wash water waste-streams depends on the types and concentrations of contaminants present. The volume reduction achieved is also important to the selection of soil washing as a potential remediation technology.

In scaling the cost and performance estimates from remedy selection testing to remedy design testing or a full-scale soil washing system, the factors for consideration are:

Performance capabilities of the soil washing process, including design parameters

- Contaminants and contaminant concentrations in the coarse soil fraction

- Contaminants and contaminant concentrations in the used wash water and in the fine soils and wastewater treatment sludges

- Risk analysis evaluation for worker and community protection

- Quantity of large rocks, debris, arid other screenable material

The design parameters for the soil washing process include soil throughput, in dry tons per hour, and optimum wash water usage in gallons per dry ton of soil. The dosage of additives, if used, mixed with wash water is also important for cost and performance estimates.

It is important to estimate the volume and physical and chemical characteristics of each soil fraction. Estimates of the volume of and contaminant concentrations in the fine soil fraction are needed to design treatment systems and estimate disposal costs. Recycled water can be used to evaluate the cost of filtration and other dewatering equipment. The ability to remove contaminants from spent wash water and recycle the water through the system is an important cost consideration.

Wash water is treated for recycle in the washing process. Treatment includes separation of fine soil particles. Other treatment steps may be necessary to remove organics, inorganics, and additive chemicals. Scale-up design requires estimates of wash water volume and quality.

Contamination in excavated soil can pose safety concerns for workers and the community. Worker protection may be required during soil excavation. The need for such protection is a site-specific decision. Health and safety plans should be prepared and risk analysis conducted for the site.

The quantity of large rocks, debris, and other screenable material that must be removed is an important measurement. While this is not a "laboratory" measurement, it is important to determine which treatment method is most suitable for preparing the bulk soil for entry into the soil washing process (i.e., screening to remove large rocks, stumps, debris, and crushing of oversize rocks, etc.).

6.2 ESTIMATION OF COSTS

Accurate cost estimates for remedy design treatability studies and full-scale remediation are crucial to the feasibility study process. Comparisons of various technologies must be based on the most complete and accurate estimates available, Remedy screening treatability studies cannot provide this type of information. Remedy selection treatability studies can provide relatively accurate cost estimates for remedy design studies. Preliminary cost estimates for full-scale remediation may be made from remedy selection data. Such estimates may be good enough for comparisons to other technologies at the same tier of testing. On this basis, the estimates can form the basis of the ROD. Remedy design studies may be necessary to provide a more accurate estimate of the eventual cost of full-scale soil washing remediation. This is especially true since soil washing will form only one component of a treatment train. The treatment costs for sludge and wastewater from the soil washing process must also be evaluated.

6.2.1 Soil Washing Remedy Design Cost Estimates

If the results of remedy selection treatability testing indicate that soil washing can be effective, consideration may be given to remedy design testing. Remedy design tests yield more accurate estimates of full-scale performance and costs. This discussion provides general guidance on the cost estimating and scheduling of remedy design soil washing demonstrations.

Few remedy design soil washing demonstrations have been done in the United States. A solid data base of cost estimating and scheduling information does not yet exist. The information in this section is largely derived from EPA RREL experience with its portable soil washing unit, informational estimates by the few manufacturers offering remedy design soil washing equipment, and recent experience with the EPA SITE Program. A summary of the performance data and a review of the technology are presented in a Soil Washing Engineering Bulletin.(12)

Remedy Design Soil Washing Equipment Availability: As of Fall 1989 only three sources of a portable remedy design soil washing units were identified:

- BioTrol, Inc., Chaska, Minnesota
- Ecova Corp., Redmond, Washington
- EPA RREL Laboratory, Edison, New Jersey

Mitarri, Inc., Golden, Colorado, reportedly plans to develop a remedy design unit. For the SITE Program, a remedy design BioTrol soil washing unit was recently demonstrated and evaluated in New Brighton, Minnesota.

Remedy Design Testing Cost: Many of the cost considerations in a remedy design soil washing test are similar to those of the remedy selection. Table 6-1 lists potential major cost estimate components in a remedy design soil washing field test. Some of the items in this table also pertain to remedy selection testing. The cost considerations include planning, treatment, laboratory testing, and report preparation. Substantial planning is necessary to assure that tests meet desired objectives. Additional insurance and permits may be required. As with remedy selection demonstrations, the analytical program can be the largest cost component. It is not unusual for the sampling, analysis, and QA activities to represent 50 to 60 percent of the total remedy design testing cost. Remedy design testing requires personnel safety protection for soil excavation and handling. Working under Level A or B protection can easily triple labor costs. The treatment and disposal of contaminated residuals (soil, sludge, water) can be a major expense. For these reasons, remedy design testing costs are highly variable depending on a variety of factors discussed above.

The cost of remedy design testing is highly site-specific and dependent upon the test objective. As a rough estimate, remedy design field tests could be expected to range from as low as $100,000 up to $500,000 (1989 costs) or more.

TABLE 6-1. Potential Major Cost Estimate Components in a Remedy Design Soil Washing Field Test

1.	Planning-- substantial advanced planning is usually necessary to assure that the demonstration proceeds smoothly and meets the desired objectives, including any necessary insurance, permits, etc.
2.	Excavation, transport (if needed), and storage (if needed) of the soil to be treated during the demonstration.
3.	Design and construction (as required) of temporary onsite support facilities, including water supply, power , wastewater discharge, storage of additive chemicals, and personnel facilities (office, storage, field testing space, restrooms, showers, etc.). A detailed sampling analysis and QAPjP is necessary.
4.	Analytical support, e.g., local laboratory, mobile field laboratory, etc. A detailed sampling analysis and QAPjP is necessary.
5.	Treatment and/or disposal of contaminated residuals, e.g., the contaminated soil fraction, sludges, screened-out debris, etc.
6.	Supply of chemicals, water, power, spare parts, personnel protection equipment, etc.
7.	Lease or rental of the remedy design unit and auxiliary equipment including transport to the site.
8.	Provision for operating, maintenance, and analytical labor. Usually, personnel are trained for handling hazardous materials safely in addition to their other job-specific qualifications.
9.	Implementation of the remedy design demonstration in accordance with the detailed Work Plan.
10.	Decontamination, demobilization, and return transport of remedy design soil washing unit and auxiliary equipment.
11.	Return of operating site to pre-agreed condition.
12.	Laboratory testing.
13.	Report preparation.

6.2.2 Full-Scale Soil Washing Cost Estimates

There are no full-scale soil washing operations in use at Superfund sites identified at the present time. A limited number of firms (e.g., Ecova, BioTrol) are marketing their soil washing processes. In Europe, full-scale soil washing facilities are operating in Germany and the Netherlands. Cost information is largely in technical articles written by representatives of the German firm, Harbauer GmbH. The capital cost of the Harbauer facility is reported to be approximately $6 million (1986 dollars) for a 15 to 20 ton/hr facility. The reported operation and maintenance (O&M) costs for processing alone at the Harbauer Site are $150 per ton of soil, including the cost of water treatment, but not including sludge disposal. If sludge weight was assumed to be 20 percent of the incoming soil weight, and sludge disposal cost assumed to be $250 per ton, the estimated cost per ton of treated soil would be about $200 including sludge disposal.

Other European soil washing operations that are less complex than the Harbauer GmbH Berlin operation report soil washing processing costs of about $80 to $120 per metric ton or $73 to $110 per ton. Their costs are generally presented in mid-1980's dollars and details of how these costs were determined are lacking. Table 6-2 lists the major cost components for a hypothetical full-scale soil washing operation.

TABLE 6-2. Major Cost Estimate Components in a Full-Scale Soil Washing Operation[a]

1. Soil excavation.
2. Transport of excavated soil to the processing unit.
3. Temporary stockpiling of excavated soil.
4. Prevention of contaminant releases to the environment during Steps 1 through 3 above due to rain, wind, volatilization, carelessness, etc.
5. Bulk soil pretreatment steps such as screening, crushing, and physicat/chemical characterization.
6. Management of the screened-out rocks, roots, debris, etc.
7. Wash water supply facilities, e.g., storage tanks, pumps, piping, controls, etc.
8. Additive (if any) supply facilities, e.g., storage tanks, pumps, piping, controls, etc.
9. The soil washing process unit, which may consist of a series of mixers, washers, screens, conveyors, cyclones, and other units. It is assumed that generally this cost will be obtained from the manufacturer.
10. Temporary stockpiling, transport, and deposition of the adequately clean, washed soil product fraction.
11. The dirty wash water treatment process, which is usually a treatment train that may include clarifiers, chemical reactors, filters, carbon contactors, dewatering presses, and tanks, etc.
12. Recycle or disposal of the treated wastewater fraction.
13. Further treatment and disposal of the dirty soil fraction.
14. Further treatment and disposal of the water treatment sludge.
15. Permitting and legal services.
16. Engineering design.
17. Service during construction.
18. Contingencies.

a. Note: where applicable, the engineer performing the cost estimate will usually break down the cost estimate components listed above into:

(1) construction (e.g., roads, foundations, buildings, etc.)

(2) process equipment (e.g., mixers, tanks, screens, pumps, clarifiers, etc,)

(3) material handling equipment (eg., power shovel, bulldozer , portable conveyor, trucks, etc.)

(4) labor (e,g., operators, supervisors, analytical, etc.), energy (e.g., electrical power, diesel fuel, etc.), utilities (e.g., water, sewage, etc.), materials (e.g., chemical additives, spare parts, etc.), and various overhead administrative and profit items

SECTION 7
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