Treatability Test Program Technical Report

In-Situ Solidification/Stabilization (ISS) Bench-Scale Testing

1010949

Treatability Test Program Technical Report

In-Situ Solidification/Stabilization (ISS) Bench-Scale Testing

1010949

Technical Update, May 2004

EPRI Project Manager

A. Coleman

Cosponsors

Public Service Electric and Gas Company (PSE&G)
80 Park Plaza
Newark, New Jersey 07102

PSE&G Principal Investigators

T. Plante
M. Guay

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

THIS DOCUMENT WAS PREPARED BY THE ORGANIZATION(S) NAMED BELOW AS AN ACCOUNT OF WORK SPONSORED OR COSPONSORED BY THE ELECTRIC POWER RESEARCH INSTITUTE, INC. (EPRI). NEITHER EPRI, ANY MEMBER OF EPRI, ANY COSPONSOR, THE ORGANIZATION(S) BELOW, NOR ANY PERSON ACTING ON BEHALF OF ANY OF THEM:

(A) MAKES ANY WARRANTY OR REPRESENTATION WHATSOEVER, EXPRESS OR IMPLIED, (I) WITH RESPECT TO THE USE OF ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, OR (II) THAT SUCH USE DOES NOT INFRINGE ON OR INTERFERE WITH PRIVATELY OWNED RIGHTS, INCLUDING ANY PARTY'S INTELLECTUAL PROPERTY, OR (III) THAT THIS DOCUMENT IS SUITABLE TO ANY PARTICULAR USER'S CIRCUMSTANCE; OR

(B) ASSUMES RESPONSIBILITY FOR ANY DAMAGES OR OTHER LIABILITY WHATSOEVER (INCLUDING ANY CONSEQUENTIAL DAMAGES, EVEN IF EPRI OR ANY EPRI REPRESENTATIVE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES) RESULTING FROM YOUR SELECTION OR USE OF THIS DOCUMENT OR ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT.

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

URS Corporation

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

ORDERING INFORMATION

Requests for copies of this report should be directed to EPRI Orders and Conferences, 1355 Willow Way, Suite 278, Concord, CA 94520. Toll-free number: 800.313.3774, press 2, or internally x5379; voice: 925.609.9169; fax: 925.609.1310.

CITATIONS

This report was prepared by:

URS Corporation
477 Congress Street, 9th Floor
Portland, Maine 04101

Principal Investigators
M. Guay
T. Plante
R. Fasano
G. Thomas
D. Ostrye

This report describes research sponsored by EPRI.

The report is a corporate document that should be cited in the literature in the following manner:

*In-Situ Solidification/Stabilization (ISS)Bench-Scale Testing of Manufactured Gas Plant (MGP) Impacted Soils***,** EPRI, Palo Alto, CA, 2004. 1010949.

PRODUCT DESCRIPTION

EPRI retained URS Corporation (URS) to perform bench-scale treatability testing to evaluate the effectiveness of using in-situ solidification/stabilization (ISS) to treat contaminated soils at former manufactured gas plant (MGP) sites. This work was co-sponsored by Public Service Electric and Gas Company (PSE&G) which is evaluating remedial options at five former MGP sites in New Jersey.

Research included a literature review of the application of ISS at former MGP sites and the development and implementation of a bench-scale laboratory testing program. Bench-scale testing was performed by URS' Geotechnical Services Laboratory in Totowa, New Jersey. This research identified and tested a number of potential solidification/stabilization (S/S) reagents to evaluate their ability to effectively reduce the leaching of MGP-related organic and inorganic contaminants, as well as to maintain a minimum compressive strength and a maximum permeability in treated soils.

Results & Findings

Through the literature review and URS' own experience in S/S, a number of S/S reagents and additives were identified for testing on MGP-impacted soils including: portland cement, masonry cement, flyash, blast furnace slag, organophillic clay and powdered activated carbon. A three-phase testing protocol was developed to identify the most promising mix design(s) applicable to affected soils at the sites evaluated. Synthetic Precipitation Leaching Procedure (SPLP) leaching tests were conducted on treated soils and the results compared to State of New Jersey Groundwater Quality Standards (GWQS). Initial bench-scale testing conducted as part of this research determined that cement alone could not adequately reduce the contaminant leaching. However, cement in combination with powdered activated carbon was able to reduce organic contaminant leaching, producing a leachate with non-detect levels for most contaminants and well below the GWQS for all target organic compounds. Leaching of inorganic constituents was also significantly reduced.

Challenges and Objectives

The primary challenge and objective of this EPRI research project was to identify S/S mix designs that could be used to treat MGP-impacted soils in-situ to reduce contaminant leaching to acceptable levels in groundwater. The challenges in obtaining this objective included identifying site conditions (i.e., geology, distribution and type of MGP constituents in soils, and target cleanup criteria), identifying commercially available media capable of treating the soils, and mimicking full-scale field conditions in a bench-scale laboratory environment.

Site conditions of subsurface information were reviewed for all five sites and a thorough field investigation and sample characterization laboratory analyses were conducted. The literature review identified the type of S/S reagents and additives potentially capable of treating the soils, and identified the ranges of reagent and additive mix proportions evaluated for ISS on other MGP sites. Cement was identified as the most commonly applied solidification reagent used alone or in combination with various additives for ISS. The bench-scale studies were conducted in a phased approach to first identify the most efficient solidification concentrations of cement addition for samples from each of the five sites. The project then evaluated the relative performance of various additives used in combination with cement on one sample from one site, and then applied the best performing cement/additive combination to samples from the other sites.

Applications, Values and Use

This research confirmed that ISS is an appropriate remedial technology to be applied at former MGP sites and, at a bench-scale identified a cement and additive combination that can significantly reduce contaminant leaching under conservative testing conditions (i.e., SPLP). As with any remedial design for in-situ treatment, site-specific factors must be carefully considered in determining the feasibility and costs of ISS application. Pilot-scale testing is recommended to optimize mix designs and demonstrate the efficacy of ISS, using mixtures derived from bench-scale test results.

EPRI Perspective

Non-aqueous phase liquid (NAPL) and inorganic impacts to soil and groundwater at former MGP sites pose a potential risk to the environment that can be difficult and expensive to remediate. Traditionally, many sites have opted to excavate and treat NAPL-impacted soils off site, and backfill with clean soil. For sites where the impacts are shallow and easy to excavate, this is often a cost-effective approach. However, for sites with a high water table, limited working area, and/or deep contamination, excavation is often impractical and prohibitively expensive. EPRI has been sponsoring research on the use of ISS at former MGP sites for several years. The bench-scale study presented in this report expands on prior research by evaluating the potential use of additives to reduce contaminant leaching better than cement alone and under conservative testing conditions. As technology demonstration requirements vary from state to state, this research provides additional evidence of the ability of cement and additives (specifically powdered activated carbon) to solidify and stabilize NAPL-impacted soils at former MGP sites.

Approach

This report presents a bench-scale study that was conducted by URS to evaluate the feasibility of applying ISS at former MGP sites to address contaminated soil. Soils from five former MGP sites in New Jersey containing varying levels of NAPL (tar, oil), benzene, toluene, ethylbenzene, and xylenes (BTEX), polycyclic aromatic hydrocarbons (PAH), and metals, and differing soil stratigraphy including sands, marsh deposits, silty sand, clays, and till were subjected to a three-

phase bench-scale testing protocol. The testing protocol was designed to first identify soil/cement mix proportions necessary to attain strength and permeability criteria for samples from each of the five sites, compare the ability of various additives to reduce contaminant leaching, and then apply the best performing cement/additive combination to soil samples from the other sites.

Keywords

In-situ solidification/stabilization
Leaching tests
MGP
NAPL

ABSTRACT

EPRI has been evaluating the feasibility of, and documenting the use of in-situ solidification/ stabilization (ISS) at former manufactured gas plant (MGP) sites as a cost-effective in-situ treatment technology. In-situ solidification is of particular interest for sites where a traditional excavation and off-site treatment/disposal remedial approach may be prohibitively expensive due to factors such as depth of contamination and/or high water table, or where a traditional excavation approach may be otherwise undesirable due to limited working areas on small sites, third party access limitations, close proximity to residential areas, high dewatering and treatment volumes, and excavation stability issues. For this project, EPRI and Public Service Electric and Gas Company (PSE&G) were interested in evaluating ISS as a potential remedial approach at five former MGP sites in northern New Jersey. This document presents results of bench-scale treatability testing conducted on contaminated soil samples from each of the five sites to assess the feasibility of using ISS at the sites by identifying cement and additive mix design(s) capable of both solidifying the soils to specified strength and permeability criteria and reducing contaminant leaching to acceptable levels.

A literature review refined the type of solidification/stabilization (S/S) reagents and additives potentially capable of treating the soils, and identified the ranges of reagent and additive mix proportions evaluated for application of ISS at other MGP sites. Bench-scale testing was conducted in a phased approach to first identify the most efficient solidification concentrations of cement addition for samples from each of the five sites, evaluating the relative performance of various additives used in combination with cement on one sample from one site, and then applying the best performing cement/additive combination to samples from the other sites. The testing conducted as part of this project showed that a combination of cement and powdered activated carbon (PAC) performed best in solidifying soils and reducing the contaminant leaching relative to state groundwater quality standards.

CONTENTS

---

1 INTRODUCTION 1-1

1.1 Background 1-1

1.2 Project Objectives 1-2

1.3 Report Organization 1-3

2 LITERATURE REVIEW AND REAGENT/ADDITIVE SELECTION 2-1

2.1 ISS Application at MGP Sites 2-1

2.2 Performance Criteria 2-4
  2.2.1 Strength 2-4
  2.2.2 Permeability 2-5
  2.2.3 Chemical Analyses 2-5
  2.2.4 Durability 2-6

2.3 S/S Reagents and Additives 2-7
  2.3.1 Literature Summary 2-7
  2.3.2 Reagent And Additive Selection 2-8

3 PROJECT SITES 3-1

3.1 Former Market Street Gas Works 3-2
  3.1.1 Site Description 3-2
  3.1.2 Sampling Locations Selection 3-4

3.2 Former Hackensack Gas Works 3-4
  3.2.1 Site Description 3-4
  3.2.2 Sampling Locations Selection 3-6

3.3 Former Front Street Gas Works 3-7
  3.3.1 Site Description 3-7
  3.3.2 Sampling Locations Selection 3-8

3.4 Former Harrison Gas Plant 3-8
  3.4.1 Site Description 3-8
  3.4.2 Sampling Locations Selection 3-10

3.5 Former Hoboken Gas Works 3-10
  3.5.1 Site Description 3-10
  3.5.2 Sampling Locations Description 3-13

4 TREATABILITY TESTING..4-1
4.1 Bench-Scale Testing Protocol 4-1
4.2 Field Sample Collection Procedures...4-2
  4.2.1 Composite Sample Preparation...4-4
4.3 Phase I – Initial Characterization...4-4
  4.3.1 Composite Sample Chemical Characterization 4-4
  4.3.2 Initial Trial Mixes and Strength Testing 4-6
  4.3.3 Phase I Results 4-7
  4.3.4 Phase I Results Interpretation 4-10
4.4 Phase II - Additive Evaluation..4-11
  4.4.1 Phase II Results 4-14
  4.4.2 Phase II Results Interpretation 4-21
4.5 Phase III – Site Evaluation 4-21
  4.5.1 Phase III Results 4-22
5 CONCLUSIONS AND RECOMMENDATIONS..5-1
5.1 Overall Treatability Test Program Conclusions and Recommendations............5-1
5.2 Site-Specific Recommendations...5-2
5.3 Full-Scale Construction Considerations..5-3
  5.3.1 ISS Costs 5-3
6 REFERENCES... 1

LIST OF FIGURES

Figure 2-1 Typical ISS Process Schematic 2-2
Figure 3-1 Market Street Site General Stratigraphy 3-3
Figure 3-2 Hackensack Site General Stratigraphy 3-5
Figure 3-3 Front Street Site General Stratigraphy...3-8
Figure 3-4 Harrison Site General Stratigraphy 3-9
Figure 3-5 Hoboken Site General Stratigraphy 3-12
Figure 4-1 Bench-Scale Testing Process Flowchart 4-3
Figure 4-2 Solidified Soil/Cement Cylinder After Curing...4-9
Figure 4-3 Solidified Soil/Cement Cylinder After UCS Test Breakage 4-9

LIST OF TABLES

Table 2-1 Summary of S/S Mix Designs Implemented at Other MGP Sites................ 2-7
Table 4-1 Composite Soil Sample Preparation 4-5
Table 4-2 Phase I Strength and Permeability Test Results... 4-8
Table 4-3 Phase I Soil Composite Chemical Characterization................................. 4-11
Table 4-4 Phase I Soil Composite Sample SPLP Analyses...................................... 4-12
Table 4-5 Phase II Additive Evaluation Physical Test Results 4-16
Table 4-6 Phase II Additive Evaluation Total Constituent Analysis........................... 4-17
Table 4-7 Phase II Additive Evaluation SPLP and TCLP Results 4-19
Table 4-8 Phase III Strength and Permeability Test Results Comparison 4-23
Table 4-9 Phase III Total Constituent Analysis Comparison 4-24
Table 4-10 Phase III SPLP Analysis Comparison.. 4-25
Table 5-1 Solidification Reagent Cost Comparison for a Hypothetical Site................ 5-4

1

INTRODUCTION

1.1 Background

EPRI has been evaluating the feasibility of, and documenting the use of in-situ solidification/ stabilization (ISS) at former manufactured gas plant (MGP) sites as a cost-effective in-situ treatment technology [1,2]. In-situ solidification is of particular interest for sites where a traditional excavation and off-site treatment/disposal remedial approach may be prohibitively expensive due to factors such as depth of contamination and/or high water table, or where a traditional excavation approach may be otherwise undesirable due to limited working areas on small sites, third party access limitations, close proximity to residential areas, high dewatering and treatment volumes, and excavation stability issues. The benefits of ISS that have been successfully demonstrated on other MGP sites include:

- Permeability reduction within the solidified soil mass that reduces groundwater flow and contaminant leaching to groundwater;
- Elimination/reduction of non-aqueous phase liquids (NAPL) by transformation, through blending with cement alone or in combination with other additives, to concentrations much less than the residual saturation point of the solidified soil matrix [5]; and
- Binding contaminants within a stable solidified soil monolith that effectively reduces contaminant leaching to groundwater.

For this project, EPRI and Public Service Electric and Gas Company (PSE&G) were interested in evaluating ISS as a potential remedial approach at five former MGP sites in northern New Jersey. The sites identified for inclusion in this evaluation are:

- Former Market Street Gas Works, Newark, New Jersey;
- Former Hackensack Gas Works, Hackensack, New Jersey;
- Former Front Street Gas Works, Newark, New Jersey;
- Former Harrison Gas Plant, Harrison, New Jersey; and,
- Former Hoboken Gas Works, Hoboken, New Jersey.

Remedial investigations have been completed at all five sites and, for the purposes of this evaluation they were considered well characterized in terms of the nature and extent of MGP-related contamination.

While ISS has not previously been applied at former MGP sites in New Jersey, in-situ and ex-situ solidification/stabilization (S/S) have been applied to soils from at least ten Superfund sites in New Jersey, at least four of which addressed volatile organic compounds (VOCs) or semi-volatile organic compounds (SVOCs) [7].

1.2 Project Objectives

The overall objective of this project was to evaluate the feasibility and potential effectiveness of ISS for the treatment of soil contaminated with organic and inorganic constituents at five former MGP sites in New Jersey. To accomplish this objective, EPRI and PSE&G required that the project include the following:

1. Evaluating the technical performance and effectiveness of the technology in attaining compliance with applicable remediation standards;
2. Testing the reliability of the technology in maintaining compliance with applicable remediation standards/criteria;
3. Determining the degree to which the technology reduces toxicity, mobility, or volume of contaminants;
4. Producing a protocol that incorporates optimal mixtures of S/S materials that can be applied by a remedial contractor during full-scale implementation;
5. Examining and describing which technology minimizes risks associated with contamination left on site, while still providing long-term protection; and,
6. Determining the potential for off-site migration of contamination from stabilized soil through erosion, subsurface migration, or via other mechanisms.

The scope of work for this project was designed to provide the information necessary to determine if ISS has the potential to meet the remediation goals for each site using:

1. Performance data from other MGP sites where ISS has been implemented demonstrating the long-term protectiveness of this technology when applied to MGP sites;
2. An evaluation of the geology and subsurface conditions as related to the efficacy of in-situ mixing technologies; and,
3. A bench-scale evaluation of commercially available solidification and/or stabilization reagents and additives in various mix proportions to assess their ability to reduce leaching and/or product migration.

1.3 Report Organization

Following this introduction, this report is presented in five sections. The literature review conducted to identify potential reagents and additives as well as bench-scale testing protocols used by others is described in Section 2, along with the basis for S/S reagent and additive selection for this project. A description of the five project sites being evaluated is provided in Section 3. The methods used to conduct laboratory bench-scale testing and the results obtained are presented in Section 4. The assessment of the study results relative to remediation of the five former MGP sites are presented in Section 5, along with conclusions and recommendations. References cited are presented in Section 6.

2

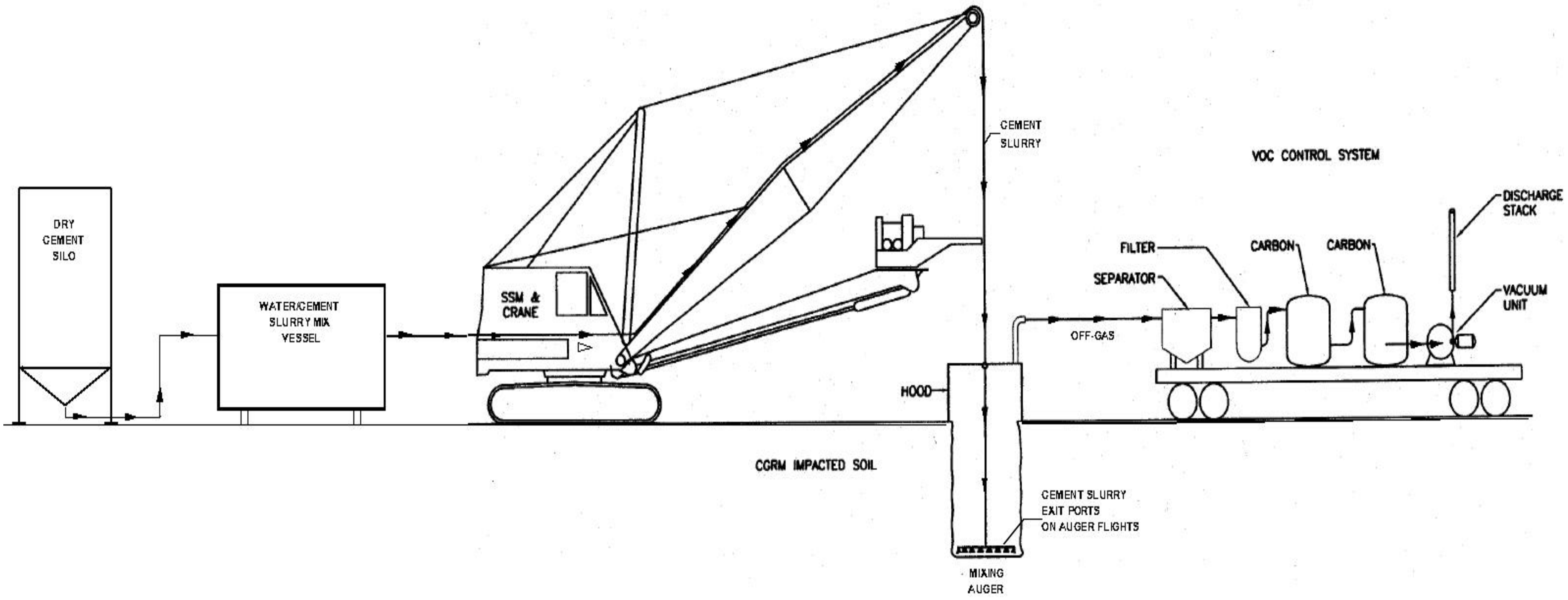
LITERATURE REVIEW AND REAGENT/ADDITIVE SELECTION

The first phase of this project consisted of a literature review to document the status of the application of ISS at MGP sites, to identify S/S reagents and additives applicable to soils containing organic and inorganic contaminants, and to identify bench-scale testing protocols and performance criteria typically applied to S/S bench-scale testing.

2.1 ISS Application at MGP Sites

ISS is typically accomplished using a large diameter (8 to 12 feet) soil-mixing auger with the reagent and additive mixture injection as a water-based grout slurry within the auger flights, as shown in Figure 2-1. Potential fugitive volatile emissions generated during the mixing process can be collected at the ground surface in a vapor shroud maintained under a slight vacuum. The collected vapors are then passed through a soil vapor treatment system. ISS has been applied to a small number of former MGP sites in the past decade. Limited published information was found on sites located in: Columbus, Georgia [1,2], Macon, Georgia [3], Augusta, Georgia [4], Exeter, New Hampshire [5], and Cambridge, Massachusetts [6]. At these sites, ISS has been successful in significantly reducing the contaminated soil's impacts to groundwater.

Figure 2-1 Typical ISS Process Schematic



In New Jersey, ISS has not been applied to former MGP sites. However, at least ten sites in New Jersey have used S/S, either in-situ or ex-situ, for the remediation of soils containing organic and/or inorganic contaminants [7]. These sites are:

- Chemical Control;
- Port Reading [i.e., Koppers site];
- NL Industries, Inc;
- Waldick Aerospace Devices, Inc;
- Asbestos Dump – New Vernon Road and White Bridge Road Cleanup;
- Nascolite Corp. – OU 2;
- American Cyanamid Co. – Group I Impoundments (11, 13, 19, and 24);
- NL Industries – OU 1;
- Caldwell Trucking;
- American Cyanamid Co. – Group II Impoundments (15, 16, 17, and 18); and,
- Cosden Chemical Coatings.

In addition to full-scale applications of ISS at MGP sites, a number of bench-scale studies on soils from former MGP sites have been conducted that provide a useful reference for the selection and evaluation of S/S reagents and additives. It is important to note that the selection of a S/S mix design depends on many factors including, but not limited to, soil types and water content; contaminant type and concentration; and remedial objectives. Remedial objectives can vary from state to state as well as from site to site within a state. Literature reviewed as part of this project contained a wide array of treatment objectives that have been applied alone or in combination at various sites including:

- Reduction in contaminant leaching of 90% or greater;
- Production of leachate concentrations less than Toxicity Characteristic Leaching Procedure (TCLP) regulatory criteria or a site-specific risk-based criteria;
- Elimination of NAPL or reduction of NAPL to below residual saturation levels;
- Achieving theoretical downgradient compliance using groundwater transport modeling to predict the groundwater concentration at a well downgradient of the solidified soil mass; and,

- Production of leachate concentrations from stabilized soil that are less than state groundwater protection criteria using Synthetic Precipitation Leaching Procedure (SPLP).

2.2 Performance Criteria

Based on the literature review conducted, project performance criteria were established for strength, permeability, leachate quality, and durability for the solidified soil/cement specimens. These criteria and their respective basis are described in the following sections.

2.2.1 Strength

Unconfined compressive strength (UCS) is the most common parameter used to evaluate the physical performance of solidified/stabilized soils for the following purposes:

- Load bearing capacity as a subgrade for pavements or environmental covers, for construction equipment access during in-situ mixing, or for foundations for buildings;
- Workability or handling ease for excavation and backfill to install utilities or foundations, spreading and subgrade shaping for landscaping, or excavation and loading for disposal;
- As a measure of adequate physical/chemical bonding in excess of that achieved with liquid sorbents alone; and,
- As an indicator of long-term durability.

The criteria selected for this project was a UCS of the solidified soil of greater than 50 pounds per square inch (psi) and less than 500 psi. URS' experience with other solidification projects in New Jersey indicates that the post-solidification strength criteria determination is site-specific. The minimum strength criteria should be sufficient for construction equipment access over solidified areas during remedial construction, for supporting environmental covers (if required), and for future low intensity site uses. The minimum 50 psi criteria is consistent with United States Environmental Protection Agency (EPA) criteria for solidified soils [12,13], UCS criteria used on some other MGP site ISS projects [1], and the strength necessary to support heavy construction equipment as quickly as possible after mixing. The maximum upper limit of UCS of 500 psi was selected to maintain the soil in an excavatable form should the need arise in the future for the construction of underground utilities, footings, or foundations that require penetration of the solidified soils.

The 50 psi criteria referenced in the EPA reports is a 28-day strength. The accelerated schedule of this project did not allow time to wait for testing of soil cylinders at 28 days because the UCS data was needed to select subsequent mix designs that were to be tested. Therefore, a 7-day strength of 50 psi was utilized.

Unconfined compressive strength was determined using American Society of Testing and Materials (ASTM) Method D2166. A pocket penetrometer was initially used in an attempt to screen out obviously weak cured specimens in lieu of the D2166 method; however, with the specimens not fully cured at 7 days, the penetrometer was found to consistently over estimate the compressive strength and its use was discontinued.

2.2.2 Permeability

Permeability testing was used to evaluate the hydraulic performance of solidified/stabilized soils. Testing focused on measuring the reduction in the amount and rate of water that passes through pores of the stabilized mass, thus reducing the leaching potential of contaminants. EPA has recommended that stabilized waste destined for land burial have a permeability of less than $1x10^{-5}$ centimeters per second (cm/sec) [13,15]. In addition, the New Jersey Department of Environmental Protection (NJDEP) Technical Requirements for Site Remediation regarding fill materials (New Jersey Administrative Code [N.J.A.C. 7:26-6.4(b)2]) require that the permeability of fill materials be no greater than the surrounding native materials. This value of $1x10^{-5}$ cm/sec is consistent with moderately impermeable natural soils, such as silty sands, silty clays and clayey sands, and is somewhat lower in permeability than the majority of the contaminated geologic stratum that would be solidified in-situ at these sites. Therefore a $1x10^{-5}$ cm/sec permeability criteria was selected for this bench-scale testing using ASTM Method D5084.

2.2.3 Chemical Analyses

There were two objectives established for the chemical analysis of solidified samples: 1) comparison of total constituent analysis in the raw composite and the cured solidified samples to assess the mechanism of treatment (e.g., encapsulation by solidification, stabilization by chemical change, or volatilization by mixing); and 2) evaluation of the ability of S/S to reduce the leachability of contaminants to acceptable levels.

The NJDEP Ground Water Quality Standards (GWQS) were selected as criteria to evaluate whether or not S/S had effectively reduced contaminant leaching to protect human health and the environment. For this study, the SPLP analysis (EPA Method 1312) was performed on samples of the solidified soils. The leachate quality was then compared with the NJDEP GWQS and Interim Specific Criteria. Since the majority of contaminated soils evaluated at the five sites were below the water table, no dilution attenuation factor (DAF) was applied to the SPLP results.

While it is a conservative approach, the SPLP test was selected as the most appropriate means of evaluating the leaching potential of soils solidified in place. This test uses a dilute inorganic acid to simulate leaching by acid rain. It is a more representative test than the TCLP test (EPA Method 1311), which was developed to simulate a more aggressive extraction that mimics the leaching of contaminants in landfills with organic, biodegradable waste which results in the production of organic acids. The SPLP test is considered conservative because the test requires that the sample be cut or crumbled to achieve a particle size less than 9.5 millimeter (mm) (0.375 inch). This destruction of the sample is not representative of field conditions and over estimates potential leaching effects into the environment. Care was taken by the analytical laboratory to avoid pulverizing or completely crushing the sample to be extracted to limit the physical destruction of the sample required by the test method. While SPLP was utilized as the primary leaching test for this study, two samples were analyzed with both the SPLP and the TCLP for comparative purposes.

Use of the SPLP test is considered a conservative approach for evaluating the leachability of soils solidified through ISS. The solidified soil mass will act as a lower permeability monolith with reduced water flow through the pore spaces as compared to the surrounding soils. The SPLP test physically breaks up this monolith (the cured soil/cement cylinder), creating a much greater surface area exposed to the leaching solution than the solidified monolith. A small proportion of other MGP sites that have evaluated the use of or implemented ISS have utilized a non-destructive static leaching test (modified from ANSI/ANS 16.1) which evaluates the leaching potential by suspending the intact soil/cement specimen in demineralized water or site groundwater for specified time periods and then analyzing the water for the contaminants of concern [1,22]. For this project, the SPLP method was considered appropriate to enable a comparative evaluation of the various cement/additive mixes under more aggressive conditions than would likely be encountered to maintain a conservative approach and, as described in the following section, to serve as a conservative surrogate for long-term durability testing. Based on the literature review, the SPLP and/or TCLP tests are the most common tests used to evaluate the efficacy of ISS technology.

2.2.4 Durability

Durability is a measure of a stabilized soil's ability to withstand repeated cycles of wet/dry conditions and freeze/thaw conditions without significantly impacting the structural integrity of the solidified soil monolith. The typical assumption is that erosion of the structural integrity of the solidified matrix could lead to increased long-term contaminant mobility. These conditions would be experienced only in the upper three to four feet of the stabilized soils. Cycles of wet/dry conditions would be minimized by future uses including covering with pavement or buildings or by placement of an environmental cover over stabilized soils at these sites. While water table fluctuation could result in a zone of long-term saturated/unsaturated cycling, these soils would not typically completely dry out. Even though some of the subject sites are adjacent to rivers with some tidal influence, the natural lag between tidal change and groundwater level change would also minimize the wet/dry cycle effect. Freeze thaw conditions would also be minimized by future pavement or building cover or by placement of an environmental cover. In addition, prior investigations at the five sites indicate that most of the contamination is deeper than the upper three to four feet of soil and well below the water table.

Given the accelerated schedule of this project, Freeze-Thaw Durability (ASTM D4842) and Wet-Dry Durability (ASTM D4843) tests were not proposed nor performed during this bench-scale study. These tests typically require a minimum of 12 cycles at each extreme condition for 24 hours each cycle, resulting in a minimum of 24 days required for these tests. These tests are typically performed on solidified cylinders that have cured for at least 28 days. Other MGP sites where cement-based solidification bench-scale testing was performed have conducted these durability tests and have shown minimal mass loss, much less than EPA's recommended maximum mass loss of 15% [1].

Since the durability tests evaluate the accelerated weathering effects on the structural integrity of the solidified soil monolith, a conservative surrogate analysis is the SPLP test that was performed to assess the leaching potential. Sample preparation involves cutting or crumbling the sample to pass a 9.5 mm standard sieve, which can be roughly compared to the matrix effects that could result from severe long-term weathering. SPLP testing provides a conservative estimate of weathering impacts because it measures leaching from a broken up piece of monolith that is much worse than any weathering breakup of stabilized soils.

2.3 S/S Reagents and Additives

2.3.1 Literature Summary

A number of reagents and additives have been evaluated and/or used for the S/S of MGP site soils. The common solidification binders identified in the literature include portland cement, flyash, blast furnace slag and cement kiln dust. Various additives have also been evaluated to improve the performance of the binder relative to one or more of the following properties: lower permeability; increased strength; and increased binding of organic or inorganic contaminants. These additives include, but are not limited to:

Flyash
Sodium bentonite
Hydrated lime
Petroleum coke
Polymer beads
Sodium silicate
Ferrous sulfate
Blast furnace slag
Organophillic clay
Powdered activated carbon (PAC)
Ground tire rubber (KAX-100)
Anthracite coal fines
Triple super phosphate

ISS bench-scale treatability studies performed on other MGP sites have typically relied on portland cement as the primary binding agent. Cement ratios (cement-to soil on a dry weight basis) as low as 7% and as high as 25% were needed to achieve target UCS [1,2,3,4,5,6]. The mix designs that have been applied full-scale on former MGP site soils, as determined from the literature review, are summarized in Table 2-1.

Table 2-1 Summary of S/S Mix Designs Implemented At Other MGP Sites

Year Completed	Location	Mix Design	Ref.
1992	Columbus, GA	10% cement	[1,2]
2001	Exeter, NH	15% cement and 5% bentonite or organophillic clay	[5]
2001	Cambridge, MA	7% cement and 2% bentonite (cement basis)	[6]
2002	Macon, GA	cement, blast furnace slag, and bentonite	[3]
2003	Augusta, GA	cement	[4]

2.3.2 Reagent and Additive Selection

The selection of reagents and additives to evaluate and apply at a given site is based, in part, on cleanup objectives. As indicated by the literature review performed for this study, these cleanup objectives and associated testing protocols vary from state to state and from site to site. To date, ISS has not been performed at former MGP sites in New Jersey. Therefore, there is no regulatory precedent for establishing the cleanup criteria using ISS for the five sites included in this project. As a consequence, this project has adopted a conservative approach to the reagent and additive selection that focused on their ability to achieve the conservatively set performance criteria described in Section 2.2.

Type I portland cement was selected as the primary solidification reagent for this evaluation based on its successful use for ISS at other MGP sites [1,2,3,4,5,6,7] and due to its ability to reduce leaching of both organic and inorganic contaminants and to improve the strength of disturbed soils. This project also evaluated the use of Type N masonry cement, because URS has successfully used masonry cement on other S/S projects to achieve a cost savings when compared to Type I portland cement. At least one study has shown the ability of masonry cement to further reduce the leaching of lead and arsenic in soils as compared to Type I portland cement [8]. Type N masonry cement typically contains approximately 45% limestone and 55% portland cement. In general, cement based binders have the ability to immobilize typical MGP contaminants through several mechanisms including pH adjustment, encapsulation, absorption, and permeability reduction.

Based the literature search and URS' S/S experience, the reagent additives selected for the bench-scale testing are listed below:

- PAC is an additive chosen because of its ability to adsorb organic contaminants and possibly "soak up" or bind some of the free oil;
- Organophillic clay (a modified bentonite clay) is an additive that also has an ability to adsorb organic contaminants, as well as further lowering the permeability of the solidified soils;
- Flyash is an additive that can adsorb some metals and organics, can reduce the amount of free water in saturated soils, and can improve strength gain, thereby potentially reducing cement requirements; and,
- Blast furnace slag is an additive that can adsorb some metals and organics, can reduce the amount of free water in saturated soils, and can improve strength gain and lower permeability, thereby potentially reducing cement requirements.

These additives are commercially available in bulk and have been shown in other studies to have some beneficial effects in S/S of soils containing organic and/or oily contaminants [1,9,10]. In addition to the above additives, the use of ferrous sulfate for arsenic stabilization and triple super phosphate (TSP) for lead stabilization was identified for use if cement alone or cement and the other additives combined did not provide sufficient reduction in the leaching of these metals.

Ferrous sulfate has been shown to be highly effective at reducing the leaching of arsenic from soils [10,11]. URS has successfully used combinations of ferrous sulfate and cement for arsenic stabilization and combinations of TSP and cement for lead stabilization on other projects.

All reagents/additives selected for use in this project are commercially available and can be supplied in bags or bulk for full-scale S/S, if ISS is ultimately chosen by PSE&G for remediation of one or more of the sites. Blast furnace slag can be especially practical as an additive because it is manufactured to be blended with portland cement to improve its properties, specifically, to increase strength, lower permeability, and increase sulfate resistance, which is important for the sites adjacent to tidally-influenced rivers.

3

PROJECT SITES

The five MGP sites investigated for this project are:

- Former Market Street Gas Works in Newark, New Jersey;
- Former Hackensack Gas Works in Hackensack, New Jersey;
- Former Front Street Gas Works in Newark, New Jersey;
- Former Harrison Gas Plant in Harrison, New Jersey; and,
- Former Hoboken Gas Works in Hoboken, New Jersey.

A summary of the site location and history, environmental setting, and contaminant distribution for each of these MGP sites is provided in the subsections that follow, along with site-specific sampling location selection rationale.

In general, soils in portions of each of the five sites contain MGP-related constituents typical of those observed at most MGP sites. These constituents include VOCs, polycyclic aromatic hydrocarbons (PAHs), and certain metals including lead and arsenic, among others. Cyanide is present in some soils with specific groundwater quality criteria exceedances noted at some of the sites. Additionally, the sites have varying levels of either free and/or residual product encountered at depths as shallow as 4 feet below ground surface (bgs) and as deep as 55 feet bgs.

The general approach used to select the sampling locations was to identify visibly contaminated areas that contained a wide range of contaminants and encompassed more than one geologic strata. ISS bench-scale testing was performed on samples collected from these areas to determine if there were physical or chemical limitations to implementing ISS at these sites, and to develop conservative mix designs for those sites where ISS is deemed feasible. These conservative mix designs could then be adjusted based on pilot and full-scale operations.

3.1 Former Market Street Gas Works

3.1.1 Site Description

The following information on site location and history, environmental setting, and contaminant distribution was obtained from the Phase 4 Remedial Investigation Report for the former Market Street Gas Works [18].

The former Market Street Gas Works was located on five separate parcels along Market Street and Raymond Boulevard in Newark, identified as Parcels 1 through 5. Parcel 1, which is bordered to the north by the Passaic River, is the downgradient portion of the site.

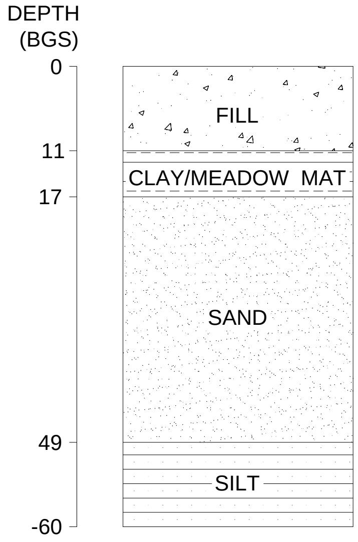
MGP operations began in 1847 on Parcel 4, and expanded through the 1880s to the other four parcels. According to available information, the coal gas process, water gas process and carbureted water gas process were used to generate manufactured gas during the MGP's years of operation. The primary raw materials historically used in the manufactured gas process at the site included coal, coke, oil, natural gas, kerosene, propane, and butane.

By 1930, the site was identified as an "emergency plant" and operations were reduced. The site was maintained as a standby plant until 1954. The aboveground MGP structures were subsequently demolished and various commercial enterprises are or have been established at various portions of the site.

Parcel 1 is predominantly flat (ground elevations range from 6.5 to 9 feet above mean sea level [MSL]) and covered with asphalt paving and a few buildings. Parcel 2 is slightly higher in elevation than Parcel 1 with ground elevations ranging from 10 to 18 feet above MSL. Approximately two-thirds of the ground surface in Parcel 2 is covered with asphalt. The ground elevations at Parcels 3 and 4 range from 16 to 19 feet above MSL and 16 to 22.5 feet above MSL, respectively. The land surface at Parcels 3 and 4 is covered with buildings and asphalt. Parcel 5 is also covered with asphalt. The Passaic River is located within 0.5 mile of all five Parcels.

Subsurface investigations conducted at the site have identified five geologic units (from ground surface downward): fill (5 to 23 feet thick); meadow mat (1 to 13 feet thick); silty sand (approximately 10 feet thick); glacial lakebed silts (approximately 25 feet thick); and bedrock. The fill material is of an industrial origin and contains ash, coal, brick, slag, concrete and other debris. The meadow mat contains organic matter and a dark gray clay. The meadow mat is present along the Passaic River but pinches out with distance inland from the river. A fine- to medium-grained sand of deltaic and estuarine origin was identified below the clay/meadow mat along the Passaic River. A fine-grained unit, identified as glacial lakebed silt, underlies the sand. Bedrock was not encountered during the on-site investigation activities. Based on regional information, bedrock in this area is believed to be shale of the Passaic Formation. Depth to bedrock in the vicinity of the site is estimated at 110 to 170 feet bgs. The general site stratigraphy is shown in Figure 3-1.

Figure 3-1 Market Street Site General Stratigraphy



Depth to groundwater ranges from 2 to 4 feet bgs near the river and from 7 to 14 feet bgs inland. Near the river, groundwater is first encountered in the fill material overlying the clay and meadow mat (water table aquifer). Below the clay and meadow mat, groundwater is present in the estuarine and glacial delta sands that comprise a single hydraulic unit. Away from the river where the meadow mat pinches out, the fill and deltaic sand comprise a single unconfined aquifer. The glacial lakebed silt serves as a confining layer across the site. Groundwater flow is generally toward the Passaic River. Groundwater elevations are tidally influenced at the site.

Onsite soils exhibit concentrations of benzene, toluene, ethylbenzene and xylenes (BTEX), PAHs and metals (arsenic, lead, mercury, nickel, and thallium) in excess of NJDEP Residential, Non-Residential and Impact to Groundwater Soil Cleanup Criteria. The vertical extent of soil contamination has been delineated. The horizontal extent of soil contamination has been partially delineated.

Groundwater exhibits evidence of impacts associated with MGP operations, gasoline releases and probable fuel oil releases. Key groundwater contaminants are benzene and naphthalene. The horizontal and vertical extent of groundwater contamination has been delineated with the exception of the northwestern corner of the site, where contamination may be due to an offsite source.

NAPL in the form of oil material and tar material is present in soils across most of the site. The horizontal and vertical extent of oil material and tar material has been delineated at the site. The greatest thicknesses of Dense Non-Aqueous Phase Liquid (DNAPL) identified at the site are in the northern portions along the Passaic River where the top of the glacial lakebed silt is deepest, indicating that DNAPL has migrated along the top of this stratum.

3.1.2 Sampling Locations Selection

Based upon a review of remedial investigation results, two sample locations on Parcel 1 were selected for collecting soil samples for bench-scale testing for ISS. These locations were selected in an attempt to evaluate more heavily contaminated areas of the site (i.e., where ISS may be applied) and to capture a range of organic and inorganic contaminants spanning more than one geologic unit. The first location, BST-01, was selected based on a combination of the following factors:

- Located within the area of the site delineated as containing NAPL along the riverfront;
- A prior sample collected from an adjacent boring contained some of the highest VOC and SVOC concentrations on the site. Total VOCs were detected at 2,063 milligrams per kilogram (mg/kg) and total SVOCs were detected at 32,000 mg/kg, with a naphthalene portion of 10,000 mg/kg; and,
- Oil sheens and/or NAPL were observed in an adjacent boring continuously between 4 feet and 55 feet bgs, encompassing all of the site stratigraphic units.

The second location selected, BST-02, was located outside the NAPL delineation area, however, it was expected to have similar stratigraphy as the BST-01 location, with lower organic contaminant levels and elevated arsenic (69 mg/kg).

3.2 Former Hackensack Gas Works

3.2.1 Site Description

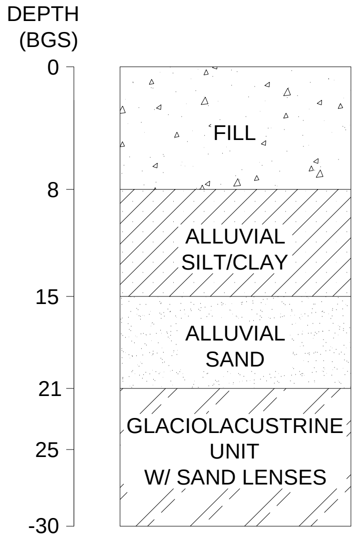
The following information on site location and history, environmental setting, and contaminant distribution was obtained from the Comprehensive Remedial Investigation Report for the former Hackensack Gas Works [16].

The former Hackensack Gas Works site consists of two non-contiguous parcels in the City of Hackensack (Parcel 1 and Parcel 2). The parcels are separated by a county road. Gas was manufactured at the site from 1867 to 1908 using the coal gas, water gas and carbureted water gas processes. By 1908, MGP production activities at the site ended; however, the site continued as a gas holder station for the storage of manufactured gas from other nearby production facilities. MGP production facilities and equipment were dismantled at the site in the 1920s. The aboveground portions of the former gas holders were razed after being taken out of service by the 1950s. An office building and electric substation are the only remaining structures at the site.

The topography of the site is generally flat. A wetland is present along the banks of Brosses Creek and the Hackensack River. At both parcels, the land surface is a combination of asphalt, gravel, buildings, and vegetation. The site contains a dense network of active subsurface natural gas distribution mains and electric transmission cables.

Subsurface investigations conducted at the site have identified five geologic units (from ground surface downward): fill (3 to 15 feet thick); alluvium (11 to 48 feet thick); glaciolacustrine sediments (64 to 82 feet thick); glacial till and bedrock. The fill at the site is composed of sands with varying amounts of silts and man-made debris including, but not limited to, brick, concrete, asphalt, coal and ash. The alluvium soils are composed of two layers: organic silt overlying fine sand. The organic silt layer appears to be continuous across Parcel 2 but discontinuous across Parcel 1. The glaciolacustrine soils observed at the site are composed of thinly varved silt and clay. Glacial till soils are composed of silty sand with some gravel. The bedrock consists of Triassic sandstones, siltstones and shales of the Passaic Formation of the Newark Supergroup. The general site stratigraphy is shown in Figure 3-2.

Figure 3-2 Hackensack Site General Stratigraphy



Groundwater is encountered within 3 to 4 feet bgs at the site. Four hydrogeological units have been identified within the site boundaries:

- Groundwater occurs in an unconfined condition within the near-surface fill and alluvium soils. The upper portion of the fill/alluvium unit has a net groundwater flow direction radially from the center of the site towards Brosses Creek and the Hackensack River. Groundwater elevations in the eastern portion of the site (Parcel 2) are tidally influenced.

- The glaciolacustrine unit acts as a confining layer (aquitard) between the overlying fill/alluvium and the underlying glacial till.

- Groundwater exists in the glacial till unit and is recharged by sources upgradient of the site and from the underlying bedrock aquifer.

VOCs, SVOCs, and metals were detected in soils at concentrations above the most stringent NJDEP soil cleanup criteria. VOC, PAH and metal exceedances are present mostly in the fill material. However, in the southeastern portion of the site, VOC and PAH exceedances have also been identified within the alluvium sand unit underlying the fill layer, but do not significantly impact the glaciolacustrine clay unit underling the alluvium sand unit.

Groundwater from the fill and alluvium units contains MGP-related constituents that exceed applicable NJDEP GWQS. Groundwater within the underlying glaciolacustrine clay unit has no exceedances of NJDEP GWQS.

NAPL was identified in the fill unit in areas associated with former MGP facilities (e.g., gas holders, tar tanks). In addition, the presence of NAPL was also detected in the deeper alluvium sand unit above the glaciolacustrine clay unit. Oil material has migrated toward the Hackensack River via a trough in the glaciolacustrine clay unit that slopes from River Street toward the Hackensack River. However, the oil material is being prevented from migrating farther north and south of the site by the higher elevation of the glaciolacustrine clay unit along the southern and northern parts of the site and under the river by a plateau that appears to be present in the glaciolacustrine clay unit adjacent to the Hackensack River.

An Interim Remedial Action was completed in mid-2003 that included the excavation, transport, treatment, disposal and backfilling of the majority of the western portion of the site (Parcel 1) to depths approaching 25 feet.

3.2.2 Sampling Locations Selection

Based upon a review of remedial investigation results, two soil sampling locations on Parcel 2 were selected for bench-scale testing for ISS. These locations were selected in an attempt to evaluate more heavily contaminated areas of the site and to capture a range of organic and inorganic contaminants spanning more than one geologic unit. The first location, BST-03, was selected based on a combination of the following factors:

- Located within the area of the site delineated as containing NAPL;
- A prior sample collected from an adjacent boring contained one of the highest napthalene concentrations found on the site (1,800 mg/kg) as well as elevated BTEX concentrations (557 mg/kg); and,
- Oil sheens and/or NAPL were observed in an adjacent boring continuously between 4 feet and 26 feet bgs, encompassing the lower portion of the fill unit, the alluvial silt/clay unit, the alluvuial sand unit, and the upper portion of the glaciolacustrine unit.

The second location selected, BST-04, was selected based on a combination of the following factors:

- Located within the area of the site delineated as containing NAPL;

- A prior sample collected from an adjacent test pit contained elevated naphthalene (670 mg/kg) and elevated lead (8,580 mg/kg) concentrations, and exhibited oil staining, a strong naphthalene odor, and an oil sheen; and,

- Oil sheens, black staining, and/or NAPL were observed in an adjacent boring continuously between 5 feet and 38 feet bgs, encompassing the lower portion of the fill unit, the alluvial silt/clay unit, the alluvuial sand unit, and the upper portion of the glaciolacustrine unit.

3.3 Former Front Street Gas Works

3.3.1 Site Description

The following information on site location and history, environmental setting, and contaminant distribution was obtained from the Remedial Action Work Plan and associated documents for the former Front Street Gas Works [19].

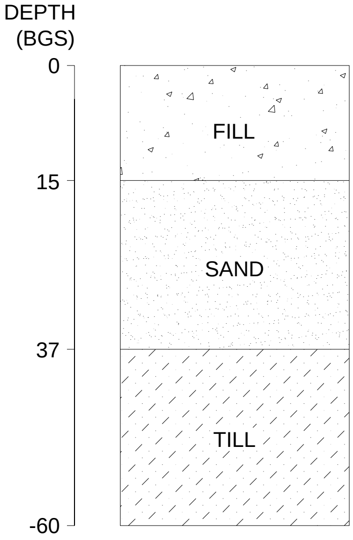
The former Front Street Gas Works is comprised of two parcels located on either side of McCarter Highway in the City of Newark. MGP operations commenced about 1870. According to available information, the coal gas process, water gas process and carbureted water gas process were used to generate manufactured gas during the MGP facility's years of operation. Gas production, purification and storage facilities were primarily located on Parcel 1 with support facilities present on Parcel 2.

In 1926, the site's status was changed to that of an auxiliary production facility. In 1937, MGP operations ceased and the removal of MGP facilities from the site was initiated, although the site continued to be used as a holder station. The holder station facilities were removed from the site in 1950. Circa 1960, the site was used as a district operation headquarters for gas department service and street operations. Over the next 35 years, the remaining former MGP facilities were removed and a storeroom, garage, underground storage tanks, pump islands, and various offices and parking areas were present on the site. In 1995, the district headquarters were relocated. By 1997, both parcels were vacant with no aboveground structures.

Limited site characterization information was available during the preparation of this report, as the remedial investigation report was not yet completed. However, it is known that the overburden geology at the site consists, from ground surface downward, of fill (10 feet thick), silty clay (0 to 8 feet thick), sand (approximately 20 feet thick), and glacial till (encountered at approximately 40 feet below ground surface). The general site stratigraphy is shown on Figure 3-3.

MGP impacts including VOCs and PAHs are present primarily in the sand unit from about 30 to 40 feet bgs. The PAH compounds present at this site include naphthalene and benzo[a]pyrene.

Figure 3-3 Front Street Site General Stratigraphy



3.3.2 Sampling Locations Selection

One sample location was selected for this site, BST-05, in an area of Parcel 2 where NAPL was encountered at adjacent boring locations at depths ranging from 24.5 feet to 43 feet bgs. The impacted soils are within the silty clay and sand units, terminating in the top 1-2 feet of the glacial till.

3.4 Former Harrison Gas Plant

3.4.1 Site Description

The following information on site location and history, environmental setting, and contaminant distribution was obtained from the Remedial Action Workplan for the former Harrison Gas Plant [17].

The site consists of a contiguous triangular-shaped parcel of land encompassing approximately 32 acres. Beginning in 1902, the site was used as a large oil and manufactured gas storage facility for the former Market Street Gas Works, located on the west side of the Passaic River in Newark. Gas manufacturing operations were constructed at the site between 1924 and 1926. The facility operated as a base load plant until approximately 1963 when it was converted to peak shaving status. The plant was retired from service in 1987.

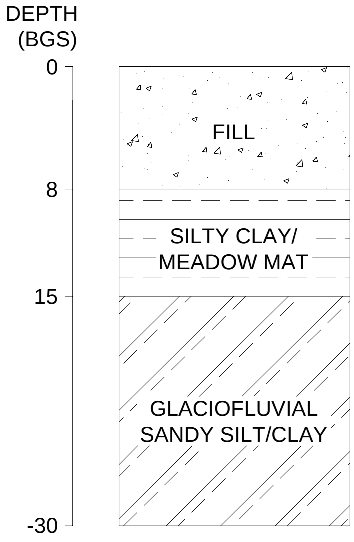
The primary gas manufacturing process used at the site was the carbureted water gas process. Raw materials included coal, coke, and oil. Tars and light oils were processed as byproducts and residuals included clinker, ash and purification wastes.

The site of the former Harrison Gas Plant presently contains headquarters facilities for PSE&G gas distribution, appliance service, and construction groups, a natural gas metering and regulating station, and a support resource recovery group. The site is underlain by an extensive network of both active utilities and inactive, abandoned-in-place piping. Foundations of former MGP structures remain in the subsurface.

The former Harrison Gas Plant site is generally flat with a maximum approximate surface elevation of 10 feet above MSL and a minimum approximate elevation of 2 feet above MSL. A wooden and concrete bulkhead exists along the eastern two-thirds of the shoreline; the remaining shoreline slopes sharply along a stabilized bank to the Passaic River. Surface water in the adjacent Passaic River is tidal. Approximately 90% of the site is located within the 100-year flood plain of the Passaic River.

From the ground surface downward, the overburden geology at the site consists of fill (3 to 13.5 feet thick), estuarine deposit silty clay marsh deposits (3 to 12 feet thick), glaciofluvial sandy silt/clay (23 to 71 feet thick), and glaciolacustrine silt and clay (24 to 80 feet thick). The fill comprises a continuous water-bearing unit (shallow aquifer) across the site with groundwater flow generally radially outward from the center of the site. The estuarine clay is a local confining unit present across the site except at the north end of the site and in the central third of the riverfront. The glaciofluvial deposits compromise a continuous water-bearing unit (intermediate aquifer) across the site with groundwater flow toward the northeast away from the Passaic River. The glaciolacustrine clay unit is laterally continuous across the site and is of sufficient thickness to act as a confining layer in the region. Both the shallow and intermediate aquifers are tidally influenced. The site general stratigraphy is shown in Figure 3-4.

Figure 3-4 Harrison Site General Stratigraphy



MGP impacts including VOCs (benzene only), PAHs, and inorganic compounds (i.e., arsenic and lead) are present in the fill. Solid tar masses and free product (DNAPL) have been delineated at the site. Groundwater contamination in both the shallow and intermediate aquifers has been delineated on-site.

3.4.2 Sampling Locations Selection

Based upon a review of remedial investigation results and discussions with PSE&G, three soil sample locations were selected for bench-scale testing for ISS. These locations were selected in an attempt to evaluate more heavily contaminated areas of the site and to capture a range of organic and inorganic contaminants and varying geology. The first location, BST-07, was selected based on a combination of the following factors:

- Located within a tar deposit in the fill strata and the upper portion of the marsh deposits; and,
- Elevated SVOCs at 25,000 mg/kg, with naphthalene at 3,600 mg/kg.

The second location, BST-06, was selected based on the following:

- Located within a tar deposit in the fill strata and the upper portion of the marsh deposits; and,
- A prior sample collected from an adjacent boring contained elevated naphthalene (3,600 mg/kg) and lead (1,600 mg/kg).

The third sample location, BST-10, was selected due to it being located along the riverfront in tar and oil impacted soils consisting of very soft fill and river sediment (organic clay). This location was requested by PSE&G to evaluate if ISS could be used along the riverfront rather than the planned excavation, due to the soft nature of the soils.

3.5 Former Hoboken Gas Works

3.5.1 Site Description

The following information on site location and history, environmental setting, and contaminant distribution was obtained from the Remedial Investigation Summary Report for the former Hoboken Gas Works [20].

The former Hoboken Gas Works site is comprised of two parcels of property identified as Block 110 and Block 116 in the City of Hoboken. Historical information indicates that the site and surrounding area was reclaimed from marshland in the early 1800s by the placement of fill materials during the urbanization of the City of Hoboken and that, prior to the construction of the former MGP, the majority of the surrounding area was urbanized and being used for a variety of industrial and commercial purposes.

MGP operations at each of the two parcels commenced in the early 1870s. Available records indicate that Block 110 contained three gas holders and an oil storage tank area. Block 116 contained a coal storage house, generator house, engine room, condenser house, two gas holders (one later used for oil storage), purifying houses, oil tank house, oil pump house, tar separator, tar house, and underground separating tank. The majority of MGP facilities were dismantled during the 1930s. The site was used as a gas holder station until the mid-1940s when all of the former MGP facilities were dismantled/demolished.

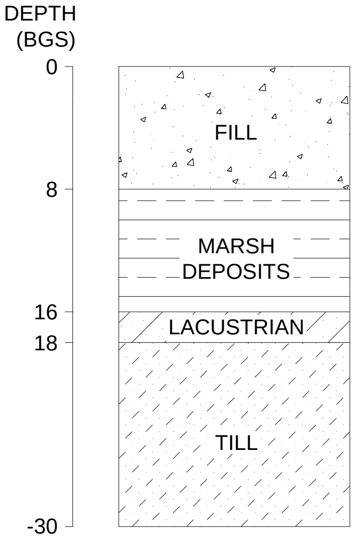
Operations conducted on Block 110 by other parties subsequent to the MGP operations included warehousing (trailer storage) and truck terminal operations, including storage of fuel oil and gasoline in underground storage tanks. Releases associated with these post-MGP operations have been documented. Currently, Block 110 is occupied by a paved lot in deteriorated condition with one building (a former truck maintenance building) in the southern portion of the property.

Operations conducted on Block 116 by other parties subsequent to the MGP operation included a gasoline/automotive service station and a paint factory. Currently, Block 116 contains a gasoline service station and associated vehicle storage area, and a small shopping plaza containing a pharmacy and a laundromat. Releases of gasoline and waste oil associated with the gasoline station’s underground storage tanks and auto-lifts have been documented.

The topography of the site is generally level with a gentle slope to the west. Surface elevations at the site range from approximately 5.5 to 11.7 feet above MSL. Most of the ground surface at the site is paved. Approximately 60% of the northwest portion of Block 110 and approximately 90% of the northwest portion of Block 116 are within the 100-year floodplain of the Hudson River, which is located less than 0.5 mile east of the site. The Hudson River is tidally influenced in this area.

From the ground surface downward, the geology of the site consists of fill (7 to 19 feet thick); marsh deposits or “meadow mat” (0 to 27 feet thick); lacustrine silty sand and clay (0 to 18 feet thick); glacial till (8 to 30+ feet thick) and bedrock. The stratigraphic units generally dip and thicken to the west and north of the site in the direction of the former marshland and Palisades Sill with the exception of the fill unit (which thins slightly as indicated by the current topography of the area) and the lacustrine deposits (which also thin in these directions, most likely associated with post-depositional erosion). The stratigraphic units beneath the site are connected due to penetration by building foundations in the area (including clustered piles extending from the ground surface to bedrock) and by the former gas holders. The general site stratigraphy is illustrated in Figure 3-5.

Figure 3-5 Hoboken Site General Stratigraphy



Groundwater beneath the site occurs under water-table conditions within the fill and marsh deposit units. The depth to groundwater ranges from 4 to 5 feet bgs, and the overall direction of groundwater flow is to the west and northwest, toward the former marshlands. The marsh deposits and lacustrine deposits are not sufficiently continuous or aerially extensive to be considered area-wide confining layers. A semi-confined deep overburden groundwater zone exists within the lacustrine and glacial deposits and in the weathered bedrock. Groundwater flow in the deep overburden groundwater zone is to the northwest following the bedrock dip.

Bedrock beneath the site consists of interbedded white sandstone and red/red brown siltstone. Geophysical studies suggest substantial historic tectonic disturbances likely associated with the intrusion of the nearby Palisades Sill. The potential for contaminant migration within the bedrock is low based on the low permeability (10^{-6} to 10^{-8} cm/sec) and the absence of significant secondary porosity features.

The primary contaminants of concern in soil and groundwater at the site are BTEX and naphthalene. The greatest amount of MGP-affected soil is present in saturated soils (below the water table), within the marsh deposits at depths generally between 10 to 20 feet bgs. Soil sample results for the saturated soils (particularly below 10 feet bgs) indicate heterogeneous contaminant distributions, likely resulting from contaminant migration/groundwater transport along pathways induced by groundwater flow. This indicates that soil sample results below the water table are influenced by groundwater contamination and flow patterns. The lateral and vertical extent of MGP–affected soil has been delineated.

The presence of NAPL is limited to a few locations at the site and on some of the properties adjacent to the site. Fingerprinting analyses indicate the presence of coal gas related material (e.g., analytical data indicating a pyrogenic source) and weathered gasoline and diesel fuel (i.e., analytical data indicating a petrogenic source) on Block 110, and both pyrogenic and petrogenic materials (including oil lubricant and hydraulic oil-type material) on Block 116.

3.5.2 Sampling Locations Description

Access to the site was limited during the field investigation portion of this project as the properties are owned by a third party. Block 110 was unavailable for sampling for this project. The boring location selected for this site on Block 116, BST-08, is located adjacent to a prior sample location that contained elevated naphthalene (1,260 mg/kg). This location exhibited oil sheens in the soils at varying depths encompassing all the site strata.

4

TREATABILITY TESTING

The bench-scale testing portion of this project was designed to address the following objectives:

1. Evaluate the ability to solidify soils in the impacted geologic stratum in-situ and meet minimum strength and permeability performance criteria using solidification reagent mixes;

2. Evaluate commercially available reagent additives for their ability to enhance the binding of organics, reduce the leachability of contaminants of concern, reduce the permeability of the solidified mass, or reduce the overall cost of solidification; and,

3. Evaluate the ability of ISS to reduce the leaching of contaminants of concern to levels protective of groundwater.

4.1 Bench-Scale Testing Protocol

URS developed a three-phase testing protocol to address project objectives in a cost-effective and timely manner. The three phases are:

- Phase I – Initial Characterization and Physical Performance Screening;

- Phase II – Reagent and Additive Evaluation; and,

- Phase III – Site Evaluation.

The objectives of the Phase I tests were to establish the chemical characteristics of each vertically composited soil sample, and to determine what percentage (by weight) of solidification reagent is necessary to achieve minimum physical performance criteria for compressive strength and permeability for each soil sample from each site.

In this phase, a maximum of 25% by weight (based on composite soil dry weight) cement addition was used. Solidified samples that did not achieve the minimum physical performance criteria at the 25% cement ratio were discontinued from further evaluation. Mix ratios above 25% become costly and create excessive volume increase that may be considered unsuitable at some sites. ISS bench-scale treatability studies performed on other MGP sites have typically found cement ratios between 10% and 25% to be sufficient [1].

In Phase II, the benefits of the various selected additives were evaluated on a soil sample from one site. The additive benefits evaluated included: reducing the amount of solidification reagent required; reducing the availability of free oil to interfere with the curing of cement; maximizing the reduction in permeability of the solidified mass; increasing the bearing capacity of the treated soil; and reducing the leachability of the target constituents from the treated soil. As cement has previously been demonstrated to be effective for ISS of MGP site soils, one of the goals of this phase was to assess additives that, used in combination with cement–based reagents, could optimize the effectiveness and minimize costs during full-scale application. The additives were blended with dry cement and water and added as grout slurry to the soil samples.

In Phase III, site soil composite samples retained through the Phase I evaluation were evaluated for the ability to apply the most promising S/S cement and additive combination identified during the Phase II evaluation.

This phased approach to the bench-scale testing followed a series of planned steps: observation and/or testing; evaluating the results of the steps; and making decisions on mix proportions for subsequent testing. Figure 4-1 illustrates this three-phase bench-scale testing process as a flowchart decision tree.

4.2 Field Sample Collection Procedures

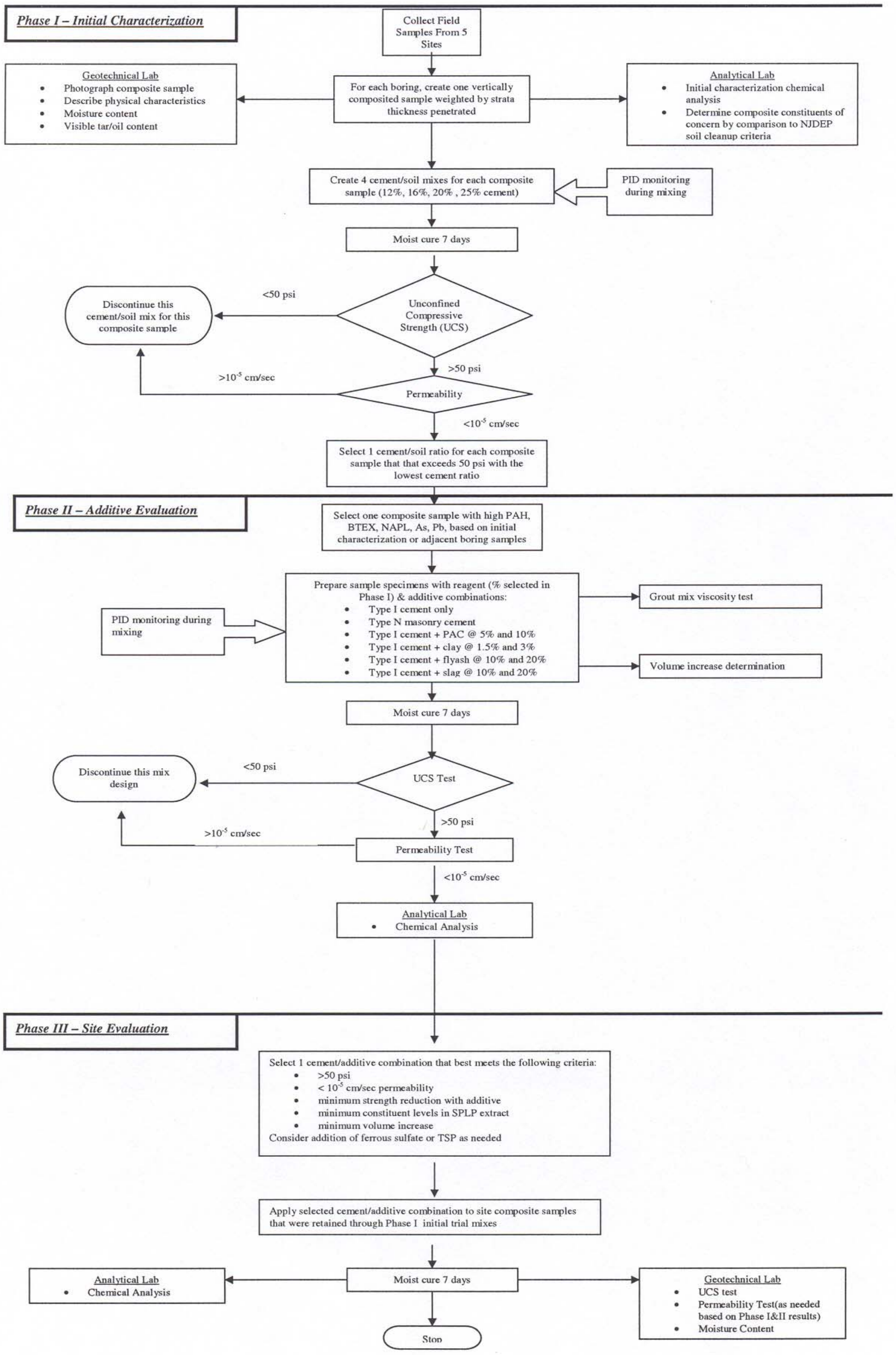
Field sample collection was conducted during the period between November 18 through 26, 2003. Soil borings were advanced and subsurface soil samples collected using a truck-mounted drill rig with hollow-stem augers. Continuous samples were obtained using a 3-inch inside diameter (ID) split-spoon sampler. Individual samples were examined for evidence of contamination (visual and olfactory) and screened for the presence of organic vapors using a photoionization detector (PID). The soils were characterized in the field as to geology, consistency, and visible evidence of MGP-related contamination (e.g., staining, oil, tar). Visual observations, odors and the results of instrumental screening were recorded on the boring logs.

At each sampling location, samples were obtained from each distinct subsurface stratigraphic unit within the depth range where historical evidence of contamination was anticipated based on adjacent prior borings and/or test pits. The soil samples were placed in separate sealed clean containers representing the discrete geologic strata.

In order to provide sufficient sample volume for the treatability testing, attempts were made to collect at least one 5-gallon pail of subsurface material from each strata encountered. If poor split-spoon recovery occured in a particular strata or the quantity of material was deemed not proportional to the percentage of that strata encountered in the boring, the sample for that particular strata was supplemented using carefully separated cuttings from the auger flights representing that strata.

The sealed sample buckets were labeled as to site, sample location, and geologic strata and transported to the geotechnical testing lab under chain of custody at the end of each day of sampling.

Figure 4-1 Bench-Scale Testing Process Flowchart



4.2.1 Composite Sample Preparation

For each boring at each site, the volume of soil recovered from each geologic strata was determined. Using the volumes recovered and the thickness of each strata to be solidified as indicated on the boring logs, a depth proportional composite sample was created that would represent vertical compositing from the ground surface (or an anticipated site construction subgrade level) to the bottom of the visually impacted soils. The appropriate volumes (representing the proportionate strata thickness) of each soil strata were blended either by hand mixing or using a soil splitter to achieve uniform mixing to the extent feasible. The appropriate blending method was determined based on soil characteristics and the relative amount of tar or oil. Clayey soils were broken up with spatulas to assist their flow through the sample splitter. The composite samples were then placed in sealed containers and labeled. The blending that occurred during sample compositing can be roughly correlated to the blending that would occur during full-scale ISS using large diameter soil augers to vertically mix individual soil columns with one or more passes. A description of the sample composite preparation for each sample location is provided in Table 4-1.

4.3 Phase I – Initial Characterization

This phase of the project was intended to provide initial physical and chemical characterization of the soils and to enable evaluation of the ability of cement to solidify the soils sufficiently to achieve the minimum strength and maximum permeability criteria. This phase also provided insight into how amenable the soil matrices were to thorough mixing with a reagent slurry.

4.3.1 Composite Sample Chemical Characterization

Immediately after preparing the soil composite sample, samples for analysis of BTEX were collected and methanol preserved in accordance with NJDEP requirements. While it was recognized that the NJDEP typically requires that VOC samples be collected as discrete samples in the field with no compositing for site characterization, it was more important for this study to establish the VOC level in the composited sample as a basis for pre- and post-solidification comparisons. Initial characterization samples were then collected from each soil for the physical and chemical analyses listed below. Sample jars were labeled, placed on ice and transported immediately to the analytical laboratory along with completed Chain-of-Custody forms.

Table 4-1 Composite Soil Sample Preparation

Sample Location	Site	Depth Interval (feet bgs)	Composite Interval Rationale	Composited Sample Description
BST-01	Market Street	7-49	Oil sheens, black staining, and hydrocarbon odors throughout the compositing interval.	silty brown sand, oily sheen observable
BST-02	Market Street	8-44	Oil sheens, black staining, and hydrocarbon odors throughout the compositing interval.	silty brown sand, no visible oil or tar impacts
BST-03	Hackensack	2-26	Oil sheens, NAPL, black staining, and hydrocarbon odors at various depths throughout the compositing interval. Sample included recovered drill cutting from this depth interval.	silty brown organic sand, slight sheen
BST-04	Hackensack	2-36	Oil sheens, black staining, and hydrocarbon odors throughout the compositing interval. Sample included recovered drill cutting from this depth interval.	silty organic clay, oily odor
BST-05	Front Street	5-45	Oil sheen and hydrocarbon odors from 30 feet to 45 feet bgs. Larger interval composited to represent full vertical mixing during ISS application.	silty reddish brown sand, oily odor, no visible oil or tar impacts
BST-06A	Harrison	2-12.5	Bottom 3+ feet was tar and clay. Composited with overlying sand and recovered drill cuttings to represent full vertical mixing and to enable adequate blending of the clay with reagents.	brown clayey organic sand, oily odor
BST-07	Harrison	2-10	NAPL encountered from 4 feet to 10 feet bgs. Drill cuttings also included in the sample.	black silty sand, oily odor, visible oil residue
BST-08	Hoboken	2-39	Oil sheens, black staining, and hydrocarbon odors throughout the compositing interval.	silty brown sand, oily odor
BST-10	Harrison	2-16	Oil sheens, black staining, and hydrocarbon odors throughout the 6 to 16-foot bgs interval. Drill cuttings were also included in the sample.	silty brown organic clay, oily odor, oil residue

Each soil composite sample was submitted to the analytical laboratory for the following chemical analyses:

- Total Constituent Analyses (TCA)
    - Moisture content
    - pH
    - BTEX (EPA Method 8260B)
    - PAHs (EPA Method 8270C)
    - Total Target Analyte List (TAL) metals (EPA Methods 6010/7471)
    - Total cyanide (CN) (EPA Method 9010)
    - Total oil &grease (EPA Method 9071B)
- SPLP (BTEX, PAHs, TAL metals, CN)
- SPLP extract pH by extraction method EPA Method 1312.

The results of this chemical characterization were used to identify the constituents of concern for each soil composite relative to the NJDEP soil cleanup criteria, and served as the basis for evaluating post-solidification test results.

4.3.2 Initial Trial Mixes and Strength Testing

Initial trial mixes were made from each composite sample using Type I portland cement alone to evaluate the strength of the stabilized soil with varying percentages of portland cement. Portland cement was the main solidification reagent for all the mixes.

Tests were run on each of the nine soil composites at portland cement to soil ratios of 12%, 16%, 20%, and 25% (dry weight basis). Selection of the soil/cement ratios was based on the range of cement used for MGP-impacted soil solidification at other sites identified during the literature search [1,2,6,10,21,22]. The mix ratios are expressed in terms of dry cement weight to dry soil weight (soil plus oil, tar, and other contaminants). A water-cement slurry was made at a ratio of 3/4:1 (by weight) to allow uniform blending of the cement with the soil and to simulate the method that would likely be used in the field during actual ISS remediation for delivery of solidification reagents to the mixing zone. The soil/cement mixtures were prepared by mixing appropriate wet weights of cement slurry and soil to achieve the target ratios. The soil/cement cylinders were created by pouring the cement/soil mix into 2-inch diameter by 4-inch long cylinder molds and tamping with a rod to remove any air voids. Prepared soil cement cylinders were moist cured for 7 days and subjected to strength and permeability testing.

4.3.3 Phase I Results

The strength and permeability test results for the composite soil samples mixed with varying proportions of cement are shown in Table 4-2. For those sample locations containing predominantly sandy or silty (non-plastic) soil, the minimum 50 psi strength was easily achieved at 7 days with a cement content of 12%, specifically composite samples from boring locations BST-01, BST-02, BST-05, and BST-08.

As the clay or organic matter content in the soil increased, the cement content required to achieve the minimum strength criteria increased, as observed with samples from borings BST-03, BST-04, BST-06A, and BST-07. The sample from boring BST-04 at the Hackensack site did not achieve the minimum strength criteria at 7 or 14 days cure time at the maximum cement content tested of 25%.

The sample collected from boring BST-10 at the Harrison site achieved a maximum 7-day strength of 7.2 psi at 25% cement, well below the 50 psi target. This sample was comprised primarily of clayey and organic fill soils and river sediments. The location of this boring was along a tidal river. While the primary cause of the low strength results appears to be the soil consistency, high dissolved solids, chloride and sulfate levels typically associated with soils subject to tidal influx may have interfered with the strength gain as well. The minimum permeability of 1×10^{-5} cm/sec was achieved for all the samples tested.

Table 4-2 Phase I Strength and Permeability Test Results

	MARKET STREET		HACKENSACK		FRONT STREET	HARRISON			HOBOKEN
SAMPLE	**BST-01**	**BST-02**	**BST-03**	**BST-04**	**BST-05**	**BST-06A**	**BST-07**	**BST-10**	**BST-08**
USCS SOIL TYPE	SM	SP	SO	OL	SP	SO	SP	SP	OL
UCS (psi) - 7 Day Cure									
12% Cement	62.1	57	24.9 [34.1[1]]	18.6 [17.43[1]]	203	22.4	16.2	2.5	57.5
16% Cement	99.3	90.1	41.3 [63.5[1]]	21.6 [28.16[1]]	223.4	29	23.9	3.4	104.8
20% Cement	188.8	117.9	64.7 [69.9[1]]	26.5 [28.26[1]]	279.6	37.6	51	4.7	140.5
25% Cement	242	256.4	100.5 [109.6[1]]	30.4 [38.21[1]]	300.7	59.9		7.2	206.5
PERMEABILITY (cm/sec)									
12% Cement	1.5E-06	8.4E-06	NT	NT	5.7E-07	NT	NT	NT	1.1E-06
16% Cement	4.0E-06	1.7E-06	NT	NT	9.9E-08	NT	NT	NT	4.8E-07
20% Cement	NT	NT	2.8E-07	NT	NT	NT	8.6E-07	NT	NT
25% Cement	NT	NT	1.2E-07	NT	NT	3.4E-06	NT	NT	NT

[1] Number in brackets represents a 14-day cure test result.

NT = Not Tested

Photographs of solidified soil specimens are provided in Figures 4-2 and 4-3. These photographs illustrate the soil "monolith" concept of the solidified soils (Figure 4-2) and the ability to encapsulate tarry or NAPL containing soils (Figure 4-3).

Figure 4-2 Solidified Soil/Cement Cylinder After Curing

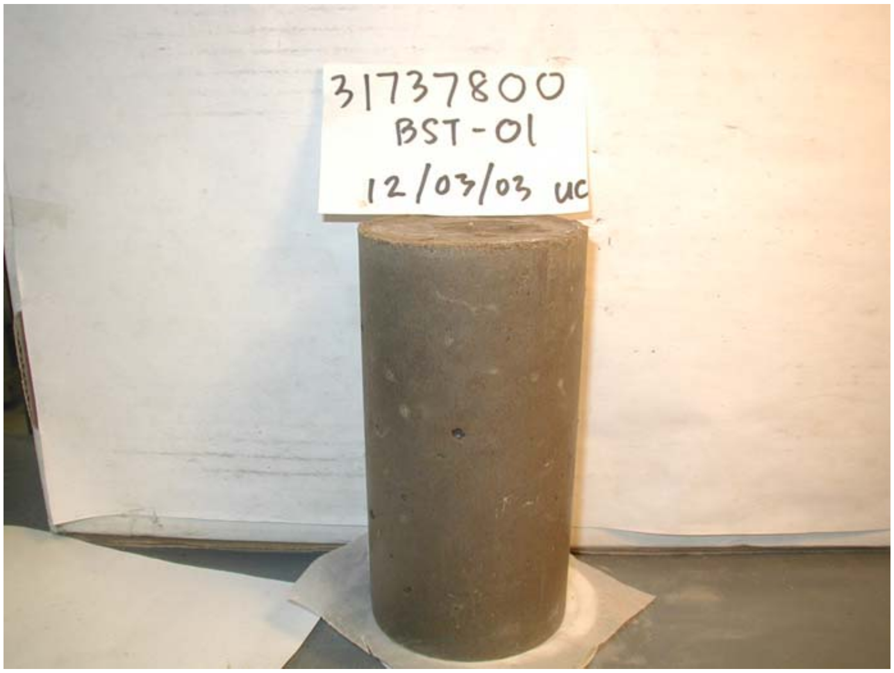


Figure 4-3 Solidified Soil/Cement Cylinder After UCS Test Breakage

The chemical characterization results for the composited soil samples are shown on Table 4-3 for the TCA and on Table 4-4 for the SPLP analysis. With the exception of sample BST-07 (Harrison site), the TCA concentrations were generally below the NJDEP Impact to Groundwater (IGW) Soil Cleanup Criteria, in spite of the presence of visible contamination in portions of each soil boring. This is attributable to the vertical compositing performed throughout the contaminated zones as well as the loss of some volatiles during initial composite mixing. This illustrates the effect that in-situ mixing will have using large diameter soil augers (i.e., the more heavily contaminated zones will be blended with less contaminated zones [vertically]). The effect of this is to create a more uniform soil mixture and contaminant distribution, allowing a mix design to be developed based on averaged concentrations, rather than the most highly contaminated sample locations, resulting in a savings in cement and additives. The BST-07 location at the Harrison site contained elevated BTEX and PAHs relative to the other composite samples from the site. This is likely because tar was encountered throughout the boring profile at this location. Those constituents exceeding the NJDEP IGW Soil Cleanup Criteria are highlighted on Table 4-3.

The SPLP analytical results completed on untreated composite samples (Table 4-4) illustrate that, with the exception of composite sample BST-05 from the Front Street site, all the samples have the potential to leach one or more contaminants of concern (primarily BTEX, PAHs, arsenic and lead) at concentrations above the respective GWQS. The Front Street site composite sample also had the lowest TCA concentrations of any composite samples analyzed, which likely contributed to the low SPLP results. This is likely the result of vertical compositing within the boring BST-05 profile that included a significant amount of overlying clean soils above the contaminated zone.

All chemical analytical data generated in this phase of the work was subjected to data validation in accordance with NJDEP requirements [23]. Data qualifiers are shown on Tables 4-3 and 4-4. In general, the data were determined useable and acceptable, however, a number of results were qualified as estimated (“J”) due to matrix interferences in some of the samples.

4.3.4 Phase I Results Interpretation

In addition to determining the contaminant levels, leachability, and ability to achieve the minimum strength and permeability criteria, the Phase I results were also used for selection of a composite sample for Phase II testing for comparison of the additive performance.

An evaluation of Phase I results, current site conditions, ownership, access, and timing issues revealed that the Front Street and Market Street sites should be retained for potential Phase II studies. After comparing composite sample results for Front Street and Market Street, the Market Street sample BST-01 indicated a higher total PAH level as well as higher total SPLP BTEX exceedances of GWQS and criteria. This composite sample also exhibited a visible oil sheen in the soil, whereas the other two composite samples exhibited no visible evidence of oil or tar impacts. The Market Street BST-01 sample was therefore selected for the additives evaluation in Phase II.

Table 4-3 Phase I Soil Composite Chemical Characterization

	IGWSCC[2]	MARKET STREET				HACKENSACK				FRONT STREET		HARRISON						HOBOKEN	
SAMPLE		**BST-01**	**Q[3]**	**BST-02**	**Q[3]**	**BST-03**	**Q[3]**	**BST-04**	**Q[3]**	**BST-05**	**Q[3]**	**BST-06A**	**Q[3]**	**BST-07**	**Q[3]**	**BST-10**	**Q[3]**	**BST-08**	**Q[3]**
% Moisture[1]		21		21		27		32		12		25		22		47		18	
Soil pH		8.3		8.2		7.9		7.5		7.9		7.6		7.4		7.3		8.1	
(Results in mg/kg)																			
Benzene	1	0.7		0.13		0.64		**10**		ND		**3.8**		**210**		ND		0.37	
Ethylbenzene	100	5.5		0.71		10		46		8		23		**240**		ND		0.84	
m&p Xylenes	67	4.3		0.18		6.4		**71**		11		13		**170**		0.18	J	3.3	
o-Xylene	67	2.5		0.16		5		39		6.3		10		**190**		ND		1.2	
Toluene	500	0.4		ND		0.2		13		ND		1.2		170		ND		0.49	
TOTAL BTEX		*13.4*		*1.18*		*22.24*		*179*		*25.3*		*51*		*980*		*0.18*		*6.2*	
Acenaphthene	100	19		2		35		34		0.069	J	18		**390**		1.8	J	12	
Acenaphthylene		3.2		0.45		3.9	J	4.1	J	0.059	J	7.2	J	430		1.9	J	5.6	J
Anthracene	100	9.2		1.6		17		20		0.062	J	9.4		**330**	J	1.7	J	18	
Benzo(a)anthracene	500	6.9		2.5		9.8		12		0.34	J	8.7	J	270	J	5.2	J	7.7	J
Benzo(a)pyrene	100	5		2.2		6		9.2	J	0.32	J	7	J	**230**	J	4.9	J	6.1	J
Benzo(b)fluoranthene	50	3.8		2.2		4.7		8.1	J	0.42	J	6.3	J	**200**	J	4.6	J	4.7	J
Benzo(g,h,I)perylene		2.4		0.58		2.4	J	4.3	J	0.14	J	2.6	J	74	J	1.5	J	2.9	J
Benzo(k)fluoranthene	500	1.9	J	1		2.3	J	3.3	J	0.17	J	2.3	J	63	J	2.5	J	3	J
Chrysene	500	6.3		2.4		9.7		12		0.42		9.2		320	J	4.9	J	7.1	J
Dibenzo(a,h)anthracene	100	0.78	J	0.36	J	0.88	J	1.5	J	0.063	J	ND		ND		ND		ND	
Fluoranthene	100	13		4		19		27		0.4		18		**600**		6	J	19	
Fluorene	100	12		1.6		22		23		0.069	J	20		**630**		2.3	J	15	
Indeno(1,2,3-cd)pyrene	500	2.1	J	0.74		2.3	J	3.9	J	0.13	J	2.2	J	58	J	1.7	J	2.5	J
Naphthalene	100	32		2.3		74		**120**		0.33	J	97		**3700**		1.9	J	58	
Phenanthrene		30		5		56		64		0.32	J	46		1400		4.1	J	46	
Pyrene	100	16		4.1		25		31		0.55		25		**810**		9.8		23	
TOTAL PAHs		*163.58*		*33.03*		*289.98*		*377.4*		*3.86*		*278.9*		*9505*		*54.8*		*230.6*	
Aluminum		3200		2800		6600		11000		6600	J	8000		4400		12000		6700	J
Antimony		ND	J	ND	J	ND		3.5		ND	J	2.8	J	14	J	ND	J	ND	J
Arsenic		ND		ND		ND		7.1		2.4		16		47		21		2.8	
Barium		21		20		53	J	110	J	55	J	68		90		160		33	J
Beryllium		ND		ND		ND		ND		ND	J	1.3	J	1.4	J	1.9	J	ND	J
Cadmium		ND		ND		ND		ND		ND		1.1	J	ND	J	6.2	J	ND	
Calcium		2000		1700		2700		8000		2800	J	3000		11000		4900		2200	J
Chromium		7.8	J	7.6	J	13		20		13		47		49		230		19	
Cobalt		3.6	J	3.3	J	5.6	J	8.6	J	5.5	J	10		5.9		13		7.1	J
Copper		ND		ND		11		48		26	J	85	J	130	J	260	J	44	J
Iron		7900		7200		12000		21000		14000	J	16000		28000		26000		14000	J
Lead		ND		ND		13		72		89	J	93	J	520	J	410	J	34	J
Magnesium		1600		1300		2800		4500		2100		2300		1300		5500		3800	
Manganese		180		130		130		320		320	J	290		150		330		180	J
Mercury		ND		ND		ND	J	0.25	J	ND		0.46	J	1.2	J	1.5	J	0.17	
Nickel		6.5		ND		11	J	16	J	12	J	610		230		78		22	J
Potassium		ND	J	ND	J	880		1300		910		1200	J	700	J	1400	J	1100	
Selenium		ND		ND		ND		ND		ND		ND		13		ND		ND	
Silver		ND		ND		ND		ND		ND		ND		ND		8.9		ND	
Sodium		ND	J	ND	J	ND		ND		ND	J	ND	J	ND	J	2900	J	ND	J
Thallium		ND		ND		ND		ND		ND		ND		ND		ND		ND	
Vanadium		ND	J	ND	J	18		30		19	J	25		42		44		24	J
Zinc		38		27		44		75		53	J	100	J	83	J	700	J	130	J
Cyanide		ND		ND		ND		3.5		ND		5.2		250		0.6		ND	
Oil & Grease		1400		180		1500		1400		850		800		9900		930		520	

[1] Moisture content determined as a percentage of the total wet soil mass.

[2] IGWSCC = NJDEP Impact to Groundwater Soil Cleanup Criteria

[3] Data qualifiers based on data validation.

J = Estimated value based on data validation and analytical reporting limits.

A **BOLD** and shaded result denotes an exceedance of the IGWSCC

ND = Not Detected above the analytical reporting limit.

Table 4-4 Phase I Soil Composite Sample SPLP Analyses

	NJ GWQS[1]	**MARKET STREET**				**HACKENSACK**				**FRONT STREET**		**HARRISON**						**HOBOKEN**	
SAMPLE		**BST-01**	**Q[3]**	**BST-02**	**Q[3]**	**BST-03**	**Q[3]**	**BST-04**	**Q[3]**	**BST-05**	**Q[3]**	**BST-06A**	**Q[3]**	**BST-07**	**Q[3]**	**BST-10**	**Q[3]**	**BST-08**	**Q[3]**
SPLP EXTRACT (ug/L)																			
Benzene	*1*	**16**		**1.2**		**4.2**		**210**		ND		**30**		**3900**		**29**		ND	
Ethylbenzene	*700*	110		11		69		460		19		300		**2300**		9.2		ND	
m&p Xylenes	*1000*	92		2.1		40		**710**		62		180		**1900**		7.4		ND	
o-Xylene	*1000*	63		3.7		37		**470**		69		170		1300		5.1		2.5	
Toluene	*1000*	12		ND		1.4	B	200	B,J	ND		16		**2400**		12		ND	
TOTAL BTEX		*293*		*18*		*151.6*		*2050*		*150*		*696*		*11800*		*62.7*		*2.5*	
Acenaphthene	*400*	ND		ND		26		55		ND		33		55		ND		64	
Acenaphthylene	*10*	ND		ND		ND		ND		ND		ND		**100**		ND		ND	
Anthracene	*2000*	ND		ND		4.2		9.9		ND		ND		9.9		ND		17	
Benzo(a)anthracene[2]	*0.2*	ND		ND		ND		ND		ND		ND		ND		ND		ND	
Benzo(a)pyrene[2]	*0.2*	ND		ND		ND		ND		ND		ND		ND		ND		ND	
Benzo(b)fluoranthene	*10*	ND		ND		ND		ND		ND		ND		ND		ND		ND	
Benzo(g,h,I)perylene	*100*	ND		ND		ND		ND		ND		ND		ND		ND		ND	
Benzo(k)fluoranthene	*1*	ND		ND		ND		ND		ND		ND		ND		ND		ND	
Chrysene	*5*	ND		ND		ND		ND		ND		ND		ND		ND		ND	
Dibenzo(a,h)anthracene[2]	*0.5*	ND		ND		ND		ND		ND		ND		ND		ND		ND	
Fluoranthene	*300*	5.1		ND		4.6		6		ND		4		5.4		ND		ND	
Fluorene	*300*	ND		ND		20		37		ND		26		60		ND		59	
Indeno(1,2,3-cd)pyrene	*10*	ND		ND		ND		ND		ND		ND		ND		ND		ND	
Naphthalene	*300*	ND		ND		ND		ND		ND		8		**750**		ND		**1700**	
Phenanthrene	*100*	ND		ND		ND		36		ND		22		63		ND		74	
Pyrene	*200*	4.8		ND		5.4		4.8		ND		4.9		5.8		ND		ND	
TOTAL PAHs		*9.9*		*0*		*60.2*		*148.7*		*0*		*97.9*		*1049.1*		*0*		*1914*	
Aluminum	*200*	1100		**1300**		**4300**		**4700**		**2800**		**1000**		93		**1500**		**2300**	
Antimony	*20*	ND		**29**		ND		ND		ND		**36**		**35**		17		**25**	
Arsenic	*8*	8.4		ND		ND		ND		ND		**19**		**15**		**12**		ND	
Barium	*2000*	260		250		360		310		270		250		120		340		220	
Beryllium	*20*	0.78		0.88		ND	J	ND	J	ND		3.2	J	2.9	J	3	J	ND	
Cadmium	*4*	1.4		1.8		ND	J	ND	J	ND		**4.7**	J	**4.8**	J	**5.1**	J	0.7	
Calcium		4200		6700		10000		18000		7800	J	21000		48000		6000		7000	J
Chromium	*100*	2.9		6.9		ND		ND		4		12		3.7		42		3.9	
Cobalt		ND		ND		ND		ND		ND		4		5.8		3.3		ND	
Copper	*1000*	15	J	63	J	ND		ND		35		12		5.8		41		26	
Iron	*300*	1700		**2300**		**4500**		**5200**		**3700**		**800**		**1000**		**1700**		**2000**	
Lead	*10*	ND		ND		ND		ND		ND		ND		ND		**40**		10	
Magnesium		1500	J	1700	J	ND	J	ND	J	1600		2600	J	5800	J	4800	J	1900	
Manganese	*50*	ND		ND		ND		ND		ND		**380**		ND		ND		ND	
Mercury	*2*	ND		ND		ND		ND		ND		ND		ND		0.31		ND	
Nickel	*100*	ND		5		ND		ND		33		**300**		15		16		ND	
Potassium		1600		1500		ND		ND		1800		1900		2200		4700		1500	
Selenium	*50*	9.8		12		ND		ND		10		29		28		12		11	
Silver	*30*	7.3	J	7.8	J	ND	J	ND	J	3		10	J	10	J	11	J	3.1	
Sodium	*50000*	8400		ND		12000		ND		ND		ND		9900		**60000**		ND	
Thallium	*10*	ND		ND		ND		ND		ND		ND		ND		ND		ND	
Vanadium		15		16		ND		ND		4.7		9		6.7		15		11	
Zinc	*5000*	ND		ND		ND		ND		81		ND		75		190		83	
Cyanide	*200*	34		ND		ND		67		ND		ND		**1400**		ND		ND	
SPLP Extract pH		8.79		8.92		7.99		7.58		8.86		7.32		5.89		8.74		7.72	

[1] Groundwater Quality Standards (GWQS) and Interim Specific Groundwater Quality Criteria (ISGWQC) utilized.

[2] Method detection limit for SPLP analysis is greater than the groundwater standard or criteria.

[3] Data qualifiers based on data validation.

J = Estimated value based on data validation and analytical reporting limits.

B = Blank contamination indicates that this result is biased high.

A **BOLD** result denotes an exceedance of the groundwater criteria.

Criteria for xylenes applies to the total of all isomers.

ND = Not Detected above the Method Detection Limit

4.4 Phase II - Additive Evaluation

The additives selected for evaluation in this project were described in Section 2.3. The selection of mix ratios for each was based on a literature search [1,2, 6,10,21,22] to identify the range of additive percentages used in other published bench-scale studies, in full-scale applications, and based on URS's experience on other sites. The reagents and additives used are further described as follows:

- Type I portland cement;
- Type N masonry cement (45% lime, 55% cement);
- Powdered activated carbon (General Carbon Corporation "GC Powdered");
- Organophillic clay (CETCO PM-199);
- Flyash (coal fired power plant flyash); and,
- Slag (NewCem ground granulated blast furnace slag from La Farge Cement)

The Phase II trial mixes were conducted on composite sample BST-01 with a 12% cement mix ratio based on the Phase I physical tests results for this sample (see Table 4-2) with the following additive ratios:

- Type I portland cement at 12%;
- Type N masonry cement at 12%;
- Type I portland cement at 12% plus PAC at 5% and 10% of the cement content, respectively;
- Type I portland cement at 12% plus organophillic clay at 1.5% and 3% of the cement content, respectively;
- Type I portland cement at 10.8% plus flyash at 1.2%;
- Type I portland cement at 9.6% plus flyash at 2.4%;
- Type I portland cement at 10.8% plus slag at 1.2%; and,
- Type I portland cement at 9.6% plus slag at 2.4%.

The additive mix ratios are expressed in terms of dry additive weight to dry soil weight (soil plus oil, tar, and other contaminants).

Water-cement-additive slurries were made in the appropriate proportions to attain the above stated ratios, to allow uniform blending of the cement and additives with the soil, and to simulate the method that will most likely be used in the field during actual ISS remediation (grout slurry injection). A Marsh Funnel was used to determine the relative viscosity of the slurry to evaluate its practical use in the field during actual ISS remediation. The slurries were mixed at a ratio of 3 parts water to 4 parts dry reagents. An estimate of the volume increase was also determined by comparing the volume of grout added to the volume of soil.

After moist curing for seven days, samples of the trial mixes were subjected to the following geotechnical tests:

- UCS (ASTM D1633); and,
- Permeability (ASTM D5084) (for samples meeting strength criteria).

The cured cylinders that met the physical performance criteria were subjected to the following analytical tests:

- TCA
    - Moisture content
    - pH
    - BTEX (EPA Method 8260B)
    - PAHs (EPA Method 8270C)
    - Total TAL metals (EPA Methods 6010/7471)
    - Total cyanide (CN) (EPA Method 9010)
    - Total oil &grease (EPA Method 9071B)
- SPLP (BTEX, PAHs, TAL metals, CN)
- SPLP extract pH by extraction method EPA Method 1312.

One sample was also selected for TCLP testing (BTEX, PAHs, TAL metals, CN and extract pH) for comparison to SPLP results.

4.4.1 Phase II Results

The strength, permeability, Marsh Funnel grout viscosity, and volumetric expansion test results for the composite soil sample BST-01 mixed with varying proportions of cement and additives are shown in Table 4-5. All samples attained the minimum strength and maximum permeability criteria, indicating that none of the additives adversely impacted these parameters. The slag mixtures produced the greatest improvement in the 7-day strength. The organophillic clay did not produce a significant reduction in permeability as might be expected, however, the amount added was small in proportion to the cement content. Marsh Funnel viscosity's ranged from 31 to 44 seconds. A Marsh Funnel viscosity of up to approximately 40 seconds is generally considered pumpable without a fluidizer or the addition of more water for grout injection applications. Volume increases ranged from 20.8% to 23.2% for the mixes tested, indicating that for most sites, some surface soils will need to be removed from the site if it is desirable that existing grades are not increased.

The TCA results for the soil/cement/additive mixes are compared to the untreated composite soil sample results in Table 4-6. In general, the BTEX compounds in the treated samples were approximately two orders of magnitude lower than were measured in the untreated soil composite sample. This is believed to be attributable to volatilization during mixing and sample preparation, as well as dilution by mixing in the cement, additives, and water as a grout slurry. Some volatilization can be expected during full-scale implementation. The need for surface vapor recovery and treatment is somewhat dependent on the depth below ground that the contaminants are located and is normally addressed during pilot-scale testing. The PAH concentrations in the treated samples were reduced by approximately 30 to 50 percent, primarily due to volatilization and blending with the cement and additives. None of the treated samples exceeded the respective state impact to groundwater criteria. The treated samples exhibited low levels of arsenic, lead, and cyanide. It appears that the cement plus PAC treated samples performed the best in binding up the total oil and grease fraction.

The SPLP analysis results for Phase II are shown in Table 4-7. Only the cement plus PAC mixture was able to reduce the BTEX and PAH leaching to below the state groundwater criteria. One unexpected result that is apparent in Table 4-7 is that all of the soil/cement/additive samples, with the exception of the cement plus 10% PAC mixture, exhibited higher leachate PAH concentrations than the soil composite sample. Other studies [22] have suggested that the elevated pH caused by the alkaline cement may, at least in the short term, increase the solubility of some organic compounds. Other studies have also found that cement alone does not reliably reduce the leaching of organics [1,22].

A quality assurance duplicate sample of the cement plus 3% organophillic clay specimen was analyzed. The relative percent difference for the VOCs and some of the PAHs were outside acceptable precision limits and therefore are qualified as estimated "J" values. A similar situation occurred with the SPLP duplicate analyses, with the inorganic results exhibiting significant differences. Of particular note is the SPLP extract pH for the duplicate sample was 5.23, as opposed to a pH of 12 in its pair and in other specimens, indicating a possible lab error.

A TCLP analysis was run on the BST01-A sample for comparison with the SPLP results. Leachate concentrations for organics were somewhat lower in the TCLP test than in the SPLP test and somewhat higher for the inorganics. This may be related to the type and strength of acid used for the respective leaching tests and how the final pH of the extracts were buffered by the soil/cement sample's inherently high pH.

Table 4-5 Phase II Additive Evaluation Physical Test Results

	12% PORTLAND CEMENT	**12% MASONRY CEMENT**	**12% PC + 5% PAC [1]**	**12% PC + 10% PAC [1]**	**12% PC + 1.5% OC [1]**	**12% PC + 3% OC [1]**	**10.8% PC +1.2% FLYASH**	**9.6% PC +2.4% FLYASH**	**10.8% PC +1.2% SLAG**	**9.6% PC +2.4% SLAG**
SAMPLE	**BST01-A**	**BST01-B**	**BST01-C1**	**BST01-C2**	**BST01-D1**	**BST01-D2**	**BST01-E1**	**BST01-E2**	**BST01-F1**	**BST01-F2**
PARAMETER										
Marsh Funnel Viscosity (Sec)	34	39	39	44	34	34	34	34	33	31
Volume Increase (%)	21.2	23.2	21.6	22	20.8	21.3	21.5	21.8	21.5	21.6
UCS (psi) - 7 Day Cure	82.6	66.1	97	74.4	95.6	90.8	71.7	77	113	113.4
PERMEABILITY (cm/sec)	2.10E-06	2.00E-06	1.80E-06	2.10E-06	1.70E-06	4.20E-06	1.80E-06	1.80E-06	2.60E-06	2.80E-06

PC = Portland Cement Type I

PAC = Powdered activated carbon

OC = Organophillic clay

[1] PAC and OC additive amounts are a percentage of the cement content.

Table 4-6 Phase II Additive Evaluation Total Constituent Analysis

		BST-01 SOIL COMPOSITE	Q[3]	12% PORTLAND CEMENT	Q[3]	12% MASONRY CEMENT	Q[3]	12% PC + 5% PAC [4]	Q[3]	12% PC + 10% PAC [4]	Q[3]	12% PC + 1.5% OC [4]	Q[3]	12% PC + 3% OC [4]	Q[3]		Q[3]	10.8% PC +1.2% FLYASH	Q[3]	9.6% PC +2.4% FLYASH	Q[3]	10.8% PC +1.2% SLAG	Q[3]	9.6% PC +2.4% SLAG	Q[3]
SAMPLE	**IGWSCC[2]**	**BST-01**		**BST01-A**		**BST01-B**		**BST01-C1**		**BST01-C2**		**BST01-D1**		**BST01-D2**		**D2 - Dup**		**BST01-E1**		**BST01-E2**		**BST01-F1**		**BST01-F2**	
PARAMETER																									
% Moisture[1]		21		18		19		19		19		20		20		19		19		18		19		19	
pH (Composite)		8.3		12		13		13		13		13		13		13		13		13		13		13	
(Results in mg/kg)																									
Benzene	1	0.7	J	ND	J	ND	J	0.0047	J	ND	J	ND	J	0.0016	J	0.0086	J	ND	J	ND	J	ND	J	ND	J
Ethylbenzene	100	5.5	J	0.028	J	0.092	J	0.014	J	0.0038	J	0.03	J	0.04	J	0.17	J	0.075	J	0.044	J	0.039	J	0.076	J
m&p Xylenes	67	4.3	J	0.023	J	0.072	J	0.01	J	0.0023	J	0.027	J	0.029	J	0.13	J	0.057	J	0.035	J	0.031	J	0.059	J
o-Xylene	67	2.5	J	0.018	J	0.049	J	0.0062	J	0.0015	J	0.02	J	0.025	J	0.092	J	0.043	J	0.029	J	0.027	J	0.044	J
Toluene	500	0.4	J	ND	J	0.0023	J	0.0021	J	ND	J	ND	J	0.002	J	0.0091	J	0.002	J	ND	J	ND	J	0.0024	J
TOTAL BTEX		*13.4*		*0.069*		*0.2153*		*0.037*		*0.0076*		*0.077*		*0.0976*		*0.4097*		*0.177*		*0.108*		*0.097*		*0.1814*	
Acenaphthene	100	19		9.9		6.3		9.9		11		7.2		9.5		9.7		8.2		7		11		5.4	
Acenaphthylene		3.2		1.4		1.4		1.4		1.5		1.4		1.8		1.4		1.5		1.5		1.7		1.1	
Anthracene	100	9.2		5.5		4.4		3.5		3.4		4.4		6.1		4.7		5.3		5.5		6.2		4.7	
Benzo(a)anthracene	500	6.9		3.6		3.5		1.5		1.2		3.3		4.7		3.1		3.9		4.5		4.7		4.2	
Benzo(a)pyrene	100	5		3		3.2		1		0.62		2.9		4		2.6		3.7		3.8		4.3		3.5	
Benzo(b)fluoranthene	50	3.8		2.8		3		1.1		0.79		2.7		3.5		2.4		3.4		3.5		3.8		3.1	
Benzo(g,h,I)perylene		2.4		1.6		1.6		0.49		0.32		1.3		1.9		1.2		1.8		1.8		2		1.7	
Benzo(k)fluoranthene	500	1.9		0.95		1.1		0.32		1.23		0.92		1.5	J	0.78	J	1.2		1.3		1.4		1.1	
Chrysene	500	6.3		3.4		3.3		1.4		1.2		3.2		4.4		2.8		3.9		4.1		4.6		4.1	
Dibenzo(a,h)anthracene	100	0.78		0.47		0.31		ND		ND		0.4		0.56		0.37		0.6		0.56		0.61		0.67	
Fluoranthene	100	13		8.1		7		4.9		4.4		6.8		9.2		6.8		8		9		10		8.2	
Fluorene	100	12		6.3		4.5		3.6		2.8		4.6		5.9		5.3		5.4		5		6.4		4	
Indeno(1,2,3-cd)pyrene	500	2.1		1.2		1.3		0.33		0.22		1.1		1.6	J	0.89	J	1.4		1.4		1.7		1.3	
Naphthalene	100	32		18		8		30		33		11		17		28		9.9		5.7		18		5.5	
Phenanthrene		30		19		15		13		14		14		19		16		17		17		21		16	
Pyrene	100	16		9.4		8.6		5.3		4.8		8.3		11		7.8		9.7		11		12		10	
TOTAL PAHs		*163.58*		*94.62*		*72.51*		*77.74*		*80.48*		*73.52*		*101.66*		*93.84*		*84.9*		*82.66*		*109.41*		*74.57*	

Table 4-6 Phase II Additive Evaluation Total Constituent Analysis (Continued)

		BST-01 SOIL COMPOSITE	Q^3	12% PORTLAND CEMENT	Q^3	12% MASONRY CEMENT	Q^3	12% PC + 5% PAC ^{4}	Q^3	12% PC + 10% PAC ^{4}	Q^3	12% PC + 1.5% OC ^{4}	Q^3	12% PC + 3% OC ^{4}	Q^3		Q^3	10.8% PC +1.2% FLYASH	Q^3	9.6% PC +2.4% FLYASH	Q^3	10.8% PC +1.2% SLAG	Q^3	9.6% PC +2.4% SLAG	Q^3
SAMPLE	IGWSCC^2	BST-01		BST01-A		BST01-B		BST01-C1		BST01-C2		BST01-D1		BST01-D2		D2 - Dup		BST01-E1		BST01-E2		BST01-F1		BST01-F2	
PARAMETER																									
Aluminum		3200		5000		4500		6300		5500		5700		4800		2900		5400		4300		5000		5700	
Antimony		ND	J	ND	J	ND	J	ND	J	ND	J	ND	J		J	ND	J	0.91	J	ND	J	ND	J	ND	J
Arsenic		ND		0.91		1.1		1		0.93		0.74		0.83		0.97		1.7		2.6		0.84		0.67	
Barium		21		26		24		32		28		30		28		19		33		32		29		35	
Beryllium		ND		0.62		0.54		0.68		0.66		0.64		0.57		ND		0.64		0.58		0.6		0.73	
Cadmium		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND	
Calcium		2000		30000		33000		42000		35000		40000		34000	J	19000	J	34000		29000		30000		35000	
Chromium		7.8	J	22	J	11	J	29	J	26	J	28	J	24	J	15	J	26	J	8.8	J	11	J	13	J
Cobalt		3.6		3.9		3.7		4.7		4.3		4.3		4.1		2.7		4.5		3.8		3.7		4.1	
Copper		ND		8.9		31		11		30		11		9.7		6.6		13		59		5.9		5.6	
Iron		7900		8800		8000		10000		9600		9900		8700		5500		9300		7000		77000		8400	
Lead		ND		5.5		3.3		4.3		4		4.1		5.5		2.9		4.3		4.4		4		4	
Magnesium		1600		3000		3900		4000		3400		3700		3200	J	1800	J	3400		2100		2400		3100	
Manganese		180		200		160		240		230		230		220		130		260		240		150		200	
Mercury		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND	
Nickel		6.5		8.7		6.5		12		10		10		9.6	J	5.6	J	11		5.3		5.4		6.1	
Potassium		ND	J	1300	J	960	J	1500	J	1400	J	1400	J	1200	J	690	J	1200	J	920	J	1000	J	1000	J
Selenium		ND		0.68		0.79		0.83		0.76		0.75		0.78		0.82		0.81		0.96		1.1		0.92	
Silver		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND	
Sodium		ND		350		280		380		360		370		320		210		310		300		310		320	
Thallium		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND	
Vanadium		ND		15		13		19		17		18		15		10		19		11		12		12	
Zinc		38	J	29	J	24	J	35	J	43	J	34	J	160	J	22	J	110	J	44	J	170	J	130	J
Cyanide		ND		14		11		11		12		8.8		12		10		9.2		6.2		15		13	
Oil & Grease		1400		460		440		240		280		1100		520	J	300	J	410		570		350		430	

[1] Moisture content determined as a percentage of the total wet soil mass.

[2] IGWSCC = NJDEP Impact to Groundwater Soil Cleanup Criteria

[3] Data qualifiers based on data validation.

[4] PAC and OC additive amounts are a percentage of the cement content.

J = Estimated value based on data validation and analytical reporting limits.

A **BOLD** and shaded result denotes an exceedance of the IGWSCC

PC = Portland Cement Type I

PAC = Powdered activated carbon

OC = Organophillic clay

ND = Not Detected above the analytical reporting limit.

Table 4-7 Phase II Additive Evaluation SPLP and TCLP Results

	NJ GWQS[1]	BST-01 SOIL COMPOSITE		12% PORTLAND CEMENT				12% MASONRY CEMENT		12% PC + 5% PAC		12% PC + 10% PAC		12% PC + 1.5% OC		12% PC + 3% OC				10.8% PC +1.2% FLYASH		9.6% PC +2.4% FLYASH		10.8% PC +1.2% SLAG		9.6% PC +2.4% SLAG	
SAMPLE		**BST-01**	**Q[3]**	**BST01-A**	**Q[3]**	***BST01-A***	**Q[3]**	**BST01-B**	**Q[3]**	**BST01-C1**	**Q[3]**	**BST01-C2**	**Q[3]**	**BST01-D1**	**Q[3]**	**BST01-D2**	**Q[3]**	**D2 - Dup**	**Q[3]**	**BST01-E1**	**Q[3]**	**BST01-E2**	**Q[3]**	**BST01-F1**	**Q[3]**	**BST01-F2**	**Q[3]**
PARAMETER																											
SPLP EXTRACT (ug/L)						***TCLP (ug/L)***																					
Benzene	*1*	**16**		ND		***ND***		ND		ND		ND		ND		ND	J	1.4	J	ND		ND		ND		ND	
Ethylbenzene	*700*	110		15		***ND***		5		5.8		ND		19		46	J	22	J	30		36		16		18	
m&p Xylenes	*1000*	92		14		***ND***		4.1		4.1		ND		17		40	J	21	J	26		33		14		17	
o-Xylene	*1000*	63		8.8		***ND***		2.6		2.3		ND		11		25	J	12	J	17		20		9.4		11	
Toluene	*1000*	12		2.1		***ND***		ND		ND		ND		ND		3.5		2.9		ND		ND		ND		ND	
TOTAL BTEX		*293*		*39.9*		*0*		*11.7*		*12.2*		*0*		*47*		*114.5*		*59.3*		*73*		*89*		*39.4*		*46*	
Acenaphthene	*400*	ND		68		***55***		80		ND		ND		68		72		73		92		110		69		110	
Acenaphthylene	*10*	ND		7.8		***4.7***		9.7		ND		ND		7.6		7.2		6.8		**11**		**13**		7.6		**13**	
Anthracene	*2000*	ND		7.9		***5.2***		9.5		ND		ND		6.4		6.8		5.2		9.7		11		7.8		12	
Benzo(a)anthracene[2]	*0.2*	ND		ND		***ND***		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND	
Benzo(a)pyrene[2]	*0.2*	ND		ND		***ND***		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND	
Benzo(b)fluoranthene	*10*	ND		ND		***ND***		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND	
Benzo(g,h,I)perylene	*100*	ND		ND		***ND***		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND	
Benzo(k)fluoranthene	*1*	ND		ND		***ND***		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND	
Chrysene	*5*	ND		ND		***ND***		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND	
Dibenzo(a,h)anthracene[2]	*0.5*	ND		ND		***ND***		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND	
Fluoranthene	*300*	5.1		4.8		***4.1***		6.8		ND		ND		4.1		4.4	J	ND	J	5.7		6.8		4.7		7	
Fluorene	*300*	ND		35		***19***		42		ND		ND		32		28		31		47		53		35		46	
Indeno(1,2,3-cd)pyrene	*10*	ND		ND		***ND***		ND		ND		ND		ND		ND		ND		ND		ND		ND		ND	
Naphthalene	*300*	ND		**390**		***250***		**440**		18		ND		**410**		**380**		**420**		**500**		**560**		**320**		**580**	
Phenanthrene	*100*	ND		38		***33***		46		ND		ND		34		36		29		48		55		39		59	
Pyrene	*200*	4.8		4.3		***4***		6.4		ND		ND		ND		ND		ND		5.4		6.3		4.3		6.4	
TOTAL PAHs		*9.9*		*555.8*		*375*		*640.4*		*18*		*0*		*562.1*		*534.4*		*565*		*718.8*		*815.1*		*487.4*		*833.4*	

Table 4-7 Phase II Additive Evaluation SPLP and TCLP Results (Continued)

	NJ GWQS[1]	BST-01 SOIL COMPOSITE		12% PORTLAND CEMENT				12% MASONRY CEMENT		12% PC + 5% PAC		12% PC + 10% PAC		12% PC + 1.5% OC		12% PC + 3% OC				10.8% PC +1.2% FLYASH		9.6% PC +2.4% FLYASH		10.8% PC +1.2% SLAG		9.6% PC +2.4% SLAG	
SAMPLE		**BST-01**	**Q[3]**	**BST01-A**	**Q[3]**	***BST01-A***	**Q[3]**	**BST01-B**	**Q[3]**	**BST01-C1**	**Q[3]**	**BST01-C2**	**Q[3]**	**BST01-D1**	**Q[3]**	**BST01-D2**	**Q[3]**	**D2 - Dup**	**Q[3]**	**BST01-E1**	**Q[3]**	**BST01-E2**	**Q[3]**	**BST01-F1**	**Q[3]**	**BST01-F2**	**Q[3]**
PARAMETER						***TCLP (ug/L)***																					
Aluminum	*200*	**1100**		**1000**		***1200***		**1000**		**1000**		**1300**		**1000**		**720**	J	**4300**	J	**980**		**1400**		**1300**		**1600**	
Antimony	*20*	ND		ND		***ND***		8.8		ND		ND		ND		ND	J	8	J	ND		ND		ND		ND	
Arsenic	*8*	**8.4**		ND		***ND***		ND		ND		ND		ND		ND	J	**24**	J	ND		ND		ND		ND	
Barium	*2000*	260		310		***220***	B	170		330		340		280		210	J	690	J	360		270		420		300	
Beryllium	*20*	0.78		ND		***ND***		ND		ND		ND		ND		ND	J	ND	J	ND		ND		ND		ND	
Cadmium	*4*	1.4		0.54		***ND***		0.49		0.63		0.78		0.47		0.81	J	3.1	J	0.58		ND		0.59		0.46	
Calcium		4200		430000		***700000***	J	330000		410000		550000		480000		370000	J	1800000	J	420000		350000		470000		360000	
Chromium	*100*	2.9		25		***ND***	J	12		18		20		18		21	J	78	J	20		2.8		3.4		2	
Cobalt		ND		ND		***ND***		ND		ND		ND		ND		ND	J	24	J	ND		ND		ND		ND	
Copper	*1000*	15		53		***ND***		100		18		23		19		12	J	33	J	13		35		15		9	
Iron	*300*	**1700**		ND		***ND***		ND		ND		ND		ND		ND	J	**4000**	J	150		ND		ND		ND	
Lead	*10*	ND		ND		***ND***	J	ND		ND		6.9		ND		6.9	J	ND	J	ND		ND		ND		ND	
Magnesium		1500		ND		***ND***		ND		ND		ND		ND		ND	J	91000	J	ND		ND		ND		ND	
Manganese	*50*	ND		ND		***ND***		ND		ND		ND		ND		ND	J	**6000**	J	ND		ND		ND		ND	
Mercury	*2*	ND	J	ND	J	***ND***		ND	J	ND	J	ND	J	ND	J	ND	J	0.18	J	ND	J	ND	J	ND	J	ND	J
Nickel	*100*	ND		8.3		***ND***		5		ND		ND		9.6		6.6	J	**230**	J	9		4.4		7.2		4.5	
Potassium		1600		35000		***43000***		28000		31000		47000		36000		30000		40000		33000		23000		31000		22000	
Selenium	*50*	9.8		11		***ND***		11		ND		ND		ND		11	J	23	J	ND		12		ND		ND	
Silver	*30*	7.3		ND		***ND***		0.9		ND		ND		ND		ND		ND		ND		ND		ND		ND	
Sodium	*50000*	8400		15000		***NA***		15000		13000		18000		15000		13000	J	18000	J	14000		12000		18000		12000	
Thallium	*10*	ND		ND		***ND***	J	ND		ND		ND		ND		ND		ND		ND		ND		ND		ND	
Vanadium		15		ND		***ND***		ND		ND		ND		ND		ND	J	52	J	ND		ND		ND		ND	
Zinc	*5000*	ND		ND		***ND***		ND		ND		ND		ND		ND	J	1600	J	ND		ND		ND		ND	
Cyanide	*200*	34		ND		***27***		12		ND		ND		ND		ND	J	18	J	ND		ND		ND		ND	
SPLP Extract pH		8.79		12.15		***11.61***		11.66		12.12		12.14		12.02		12.18		5.23		12.13		12.06		12.13		12.12	

[1] Groundwater Quality Standards (GWQS) and Interim Specific Groundwater Quality Criteria (ISGWQC) utilized.

[2] Method detection limit for SPLP analysis is greater than the groundwater standard or criteria.

[3] Data qualifiers based on data validation.

J = Estimated value based on data validation and analytical reporting limits.

B = Blank contamination indicates that this result is biased high.

A **BOLD** result denotes an exceedance of the groundwater criteria.

Criteria for xylenes applies to the total of all isomers.

ND = Not Detected above the
Method Detection Limit

NA = Not Analyzed

All chemical analyses data generated in this phase of the work were subjected to data validation in accordance with NJDEP requirements [23]. Data qualifiers are shown on Tables 4-6 and 4-7. In general, the data were determined useable and acceptable, however, a number of results were qualified as estimated ("J") due to matrix interferences or duplicate precision within some of the duplicate sample sets.

4.4.2 Phase II Results Interpretation

The results of this phase clearly show that the cement plus PAC mix provided the best overall leaching reduction, achieving SPLP leachate concentrations below GWQS and criteria for all constituents. This mix ratio of cement plus 10% PAC based on the weight of cement used was selected for the Phase III evaluation. None of the composite soil samples exhibited lead or arsenic concentrations that could not be stabilized by the cement and additive combinations used. Therefore, the use of ferrous sulfate or TSP did not appear to be warranted based on the Phase II results.

4.5 Phase III – Site Evaluation

Based on the results of Phase II, the suitability of some of the sites for solidification based on physical constraints identified in Section 4.3, and the unexpected apparent increase in leaching for many of the solidified samples as compared to the soil composite sample, the Phase III protocol was modified to accomplish the following:

1. Re-analyze the Market Street BST-01 soil composite sample for total BTEX and PAHs, and SPLP BTEX and PAHs. The objective of this re-analysis of the composite soil sample was to verify the lab results obtained in Phase I for this sample.

2. Test an aged treated sample of BST-01 for UCS, pH, and SPLP BTEX and SPLP PAHs for comparison to the 7-day cure results obtained in Phases I and II for a 12% cement/soil mix with no additives to evaluate how the longer curing time affects the results.

3. Prepare samples from Hackensack (BST-03) and Front Street (BST-05) with the cement/PAC solidification mix. A mix of 18% cement + 10%PAC (cement basis) was prepared for the BST-03 sample. Two specimens were created for the Front Street site BST-05: 12% cement + 10%PAC (cement basis) and 8% cement + 10%PAC (cement basis). This provided for a baseline comparison to the Phase I and Phase II testing for the percent cement used, as well as an evaluation of the ability of the mix with the lower cement content to meet the minimum strength and permeability criteria, since the 12% cement sample had a 2-day Phase I strength of 203 psi, well above the 50 psi minimum criteria. The untreated composite soil samples were re-tested for SPLP BTEX and PAHs due to the time that had lapsed since they were first characterized. The solidified soil samples, after curing for 7 days, were then tested for SPLP BTEX and PAHs. One treated sample (BST-05) was also submitted for TCLP BTEX and PAHs.

These analyses were intended to test the suitability of the cement/additive combination that performed the best in Phase II to other site samples with different levels of BTEX and PAHs and different soil characteristics.

4.5.1 Phase III Results

The results of the strength and permeability test comparisons are shown on Table 4-8. For the Market Street sample, a 78-day cure time resulted in a UCS of 141.2 psi, as compared to an 82.6 psi strength at 7-days, illustrating the long-term strength gain typical of portland cement based mixtures. For the Hackensack sample BST-03, the 18% cement plus 10% PAC mixture resulted in a UCS of 53.2 psi, exceeding the minimum strength criteria of 50 psi. For the Front Street sample BST-05, both the 8% and 12% cement and PAC mixtures resulted in strengths exceeding the 50 psi criteria. The permeability of the 8% cement plus 10% PAC mixture was 3.5×10^{-7} cm/sec, significantly lower than the maximum permeability set for the project of 1×10^{-5} cm/sec.

Table 4-9 shows the TCA results for the re-analyzed Market Street BST-01 sample. VOCs were not detected in the re-analysis and the total PAHs were approximately 60% of the original concentration. The duplicate composite reanalysis had poor precision for the PAHs. It is apparent that the amount of time that passed between the initial composite preparation in November and the reanalysis in February, as well as the sample disturbance resulting from creating the Phase II soil/cement specimens, resulted in degredation of the soil composite. Additionally, soil heterogeneities and matrix effects during laboratory analysis may account for some variability in the results as well.

The soil composite re-analysis for both the Market Street BST-01 sample and the Front Street BST-05 sample both exhibited volatilization losses due to extended storage as evidenced by the lack of BTEX and PAHs in the SPLP extracts illustrated on Table 4-10. Therefore, evaluation of the cement/PAC mix on the Front Street sample as well as a comparison of the SPLP and TCLP test results was inconclusive. A volatiles loss due to extended storage was also observed in the Hackensack BST-03 sample; however, there were detectable levels of BTEX and PAHs still present. The cement/PAC mix was successful in reducing the leaching of BTEX and PAHs to non-detect levels except for ethylbenzene at 1.7 micrograms per liter, well below the NJDEP GWQS.

All chemical analyses data generated in this phase of the work were subjected to data validation in accordance with NJDEP requirements [23]. Data qualifiers are shown on Tables 4-6 and 4-7. In general, the data were determined useable and acceptable; however, a small number of results were qualified as estimated (“J”) due to duplicate precision within some of the duplicate sample sets.

Table 4-8 Phase III Strength and Permeability Test Results Comparison

SITE	**MARKET STREET**			**HACKENSACK**			**FRONT STREET**	
	Phase I Soil/Cement 7-Day Cure	**Phase II Soil/Cement 7-Day Cure**	**Phase I Soil/Cement 78-Day Cure**	**Phase I Soil/Cement 7-Day Cure**	**Phase I Soil/Cement 14-Day Cure**	**Phase III Cement Plus PAC 7-day Cure**	**Raw Composite**	**Phase III Cement Plus PAC 7-day Cure**
SAMPLE	**BST-01**	**BST01-A**	**BST-01**	**BST-03**	**BST-03**	**BST-03**	**URS-BST-05**	**URS-BST-05**
PARAMETER								
UCS (psi)								
8% PC + 10% PAC(cement basis)	NS	NS	NS	NS	NS	NS	NS	124.1
12%PC	62.1	82.6	141.2	24.9	34.1	NS	203	NS
12% PC + 10% PAC(cement basis)	NS	NS	NS	NS	NS	NS	NS	366.2
16% PC	99.3	NS	NT	41.3	63.5	NS	223.4	NS
18% PC + 10% PAC(cement basis)	NS	NS	NS	NS	NS	53.2		NS
20% PC	188.8	NS	NT	64.7	69.9	NS	279.6	NS
25% PC	242	NS	NT	100.5	109.6	NS	300.7	NS
PERMEABILITY (cm/sec)								
8% PC + 10% PAC(cement basis)	NS	NS	NS	NS	NS	NS	NS	3.50E-07
12%PC	1.50E-06	2.10E-06	NT	NT	NT	NS	5.80E-07	NS
16% PC	4.00E-06	NS	NT	NT	NT	NS	9.90E-08	NS
20% PC	NT	NS	NT	2.82E-07	NT	NS	NS	NS
25% PC	NT	NS	NT	1.16E-07	NT	NS	NS	NS

PC = Portland Cement Type I

PAC = Powdered activated carbon

NT = Not Tested

NS = No Specimen Prepared

Table 4-9 Phase III Total Constituent Analysis Comparison

SITE		**MARKET STREET**					
		Phase I Soil Composite	**12% Portland Cement**	**Composite Reanalysis 2/18/04**	**Q[3]**	**Duplicate Composite Reanalysis 2/18/04**	**Q[3]**
SAMPLE	**IGWSCC[2]**	**URS-BST-01**	**BST01-A**	**URS-BST-01**		**URS-BST-01**	
PARAMETER							
% MOISTURE [1] (Composite)		21	18	17		15	
pH (Composite)		8.3	12	NT		NT	
(Results in mg/kg)							
Benzene	1	0.7	ND	ND		ND	
Ethylbenzene	100	5.5	0.028	ND		ND	
m&p Xylenes	67	4.3	0.023	ND		ND	
o-Xylene	67	2.5	0.018	ND		ND	
Toluene	500	0.4	ND	ND		ND	
TOTAL BTEX		*13.4*	*0.069*	*0*		*0*	
Acenaphthene	100	19	9.9	5.8	J	13	J
Acenaphthylene		3.2	1.4	1.9		2.3	
Anthracene	100	9.2	5.5	4.1		6.7	
Benzo(a)anthracene	500	6.9	3.6	3.9		6.5	
Benzo(a)pyrene	100	5	3	4.8		5.8	
Benzo(b)fluoranthene	50	3.8	2.8	4.4		5.1	
Benzo(g,h,I)perylene		2.4	1.6	2.6		3.1	
Benzo(k)fluoranthene	500	1.9	0.95	1.1		1.8	
Chrysene	500	6.3	3.4	4		5.8	
Dibenzo(a,h)anthracene	100	0.78	0.47	1		0.97	
Fluoranthene	100	13	8.1	6.8	J	10	J
Fluorene	100	12	6.3	4.8		9.6	
Indeno(1,2,3-cd)pyrene	500	2.1	1.2	2.1		2.6	
Naphthalene	100	32	18	4.5	J	18	J
Phenanthrene		30	19	11	J	20	J
Pyrene	100	16	9.4	8.4		14	
TOTAL PAHs		*163.58*	*94.62*	*71.2*		*125.27*	

[1] Moisture content determined as a percentage of the total wet soil mass.

[2] IGWSCC = NJDEP Impact to Groundwater Soil Cleanup Criteria

[3] Data qualifiers based on data validation.

J = Estimated value based on data validation and analytical reporting limits.

A **BOLD** result denotes an exceedance of the IGWSCC

ND = Not Detected above the analytical reporting limit.
NT = Not Tested

Table 4-10 Phase III SPLP Analysis Comparison

SITE		**MARKET STREET**					**HACKENSACK**			**FRONT STREET**				
		Phase I Soil Composite	**12% Portland Cement**	**Composite Reanalysis 2/18/04**	**Duplicate Composite Reanalysis 2/18/04**	**12% PC @ 77 Days**	**Phase I Soil Composite**	**Composite Reanalysis 2/18/04**	**18%PC w/10%PAC**	**Phase I Soil Composite**	**Composite Reanalysis 2/18/04**	**8%PC w/10%PAC**	**8%PC w/10%PAC**	**12%PC w/10%PAC**
SAMPLE	**NJ GWQS[1]**	**BST-01**	**BST01-A**	**BST-01**	**BST-01**	**BST01-A**	**BST-03**	**BST-03**	**BST-03**	**BST-05**	**BST-05**	**BST-05**	**BST-05**	**BST-05**
PARAMETER														
SPLP EXTRACT (ug/L)													***TCLP***	
Benzene	*1*	**16**	ND	ND	ND	ND	**4.2**	ND	ND	ND	ND	ND	***ND***	ND
Ethylbenzene	*700*	110	15	ND	ND	57	69	11	1.7	19	ND	ND	***ND***	ND
m&p Xylenes	*1000*	92	14	ND	ND	44	40	1.7	ND	62	ND	ND	***ND***	ND
o-Xylene	*1000*	63	8.8	ND	1.7	28	37	7.1	ND	69	ND	ND	***ND***	ND
Toluene	*1000*	12	2.1	ND	ND	1.9	1.4	1.7	ND	ND	ND	ND	***ND***	ND
TOTAL BTEX		*293*	*39.9*	*0*	*1.7*	*130.9*	*151.6*	*21.5*	*1.7*	*150*	*0*	*0*	***0***	*0*
Acenaphthene	*400*	ND	68	ND	ND	54	26	37	ND	ND	ND	ND	***ND***	ND
Acenaphthylene	*10*	ND	7.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	***ND***	ND
Anthracene	*2000*	ND	7.9	ND	ND	ND	4.2	ND	ND	ND	ND	ND	***ND***	ND
Benzo(a)anthracene[2]	*0.2*	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	***ND***	ND
Benzo(a)pyrene[2]	*0.2*	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	***ND***	ND
Benzo(b)fluoranthene	*10*	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	***ND***	ND
Benzo(g,h,I)perylene	*100*	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	***ND***	ND
Benzo(k)fluoranthene	*1*	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	***ND***	ND
Chrysene	*5*	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	***ND***	ND
Dibenzo(a,h)anthracene[2]	*0.5*	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	***ND***	ND
Fluoranthene	*300*	5.1	4.8	ND	ND	ND	4.6	ND	ND	ND	ND	ND	***ND***	ND
Fluorene	*300*	ND	35	ND	ND	21	20	14	ND	ND	ND	ND	***ND***	ND
Indeno(1,2,3-cd)pyrene	*10*	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	***ND***	ND
Naphthalene	*300*	ND	**390**	ND	ND	**510**	ND	ND	ND	ND	ND	ND	***ND***	ND
Phenanthrene	*100*	ND	38	ND	ND	23	ND	ND	ND	ND	ND	ND	***ND***	ND
Pyrene	*200*	4.8	4.3	ND	ND	ND	5.4	ND	ND	ND	ND	ND	***ND***	ND
TOTAL PAHs		*9.9*	*555.8*	*0*	*0*	*608*	*60.2*	*51*	*0*	*0*	*0*	*0*	***0***	*0*
EXTRACT pH		8.79	12.15	7.42	7.38	11.88	7.99	6.92	12.03	8.86	6.82	11.74	***11.3***	12.03

[1] Groundwater Quality Standards (GWQS) and Interim Specific Groundwater Quality Criteria (ISGWQC) utilized.

[2] Method detection limit for SPLP analysis is greater than the groundwater standard or criteria.

[3] Data qualifiers based on data validation.

A **BOLD** result denotes an exceedance of the groundwater criteria.
Criteria for xylenes applies to the total of all isomers.
ND = Not Detected above the Method Detection Limit

5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Overall Treatability Test Program Conclusions and Recommendations

From the bench-scale testing conducted as part of this project, the following general conclusions can be drawn:

- Cement based S/S can be used to improve the strength and lower the permeability of various soil types from sands to silts, clays, and marsh deposits. The vertical compositing across geologic strata provides a reasonable representation of field mixing conditions and is similar to mixing induced with in-situ auger mixing. Auger mixing can aid in shearing and mixing clay soils with more granular non-cohesive soils and in mixing of the cement and additives with the soil.
- Some loss of VOCs due to volatilization during mixing was observed and can be expected to occur during full-scale implementation.
- The amount of cement that was required to solidify the soils to meet a minimum 50 psi strength criteria appears to be directly related to the relative amount of clay or organic deposits (peat, meadow mat) present (i.e., higher clay/organic content required higher cement percentage).
- Vertical compositing across geologic strata, as would be induced with in-situ auger mixing, appears to create a more even distribution of contaminant concentrations within the S/S treatment zone, potentially allowing for less variation in the mix design to address multiple contaminated site strata.
- Cement alone was not able to reduce the leaching of MGP-related organic contaminants (BTEX and PAHs).
- Of the additives evaluated, only PAC was successful in significantly lowering the solidified soil’s leachability, to non-detect levels in most cases, and well below the state GWQS. Since the tests conducted were based on 7-day cure times, evaluation at longer curing times may be necessary for a given site to demonstrate the long-term effectiveness of this mix design.

- No significant difference between SPLP and TCLP leaching tests was observed in the paired test run, although the SPLP test is more representative of precipitation and groundwater induced leaching in a natural (i.e., non-landfill) environment.

It is important to note that the SPLP leaching test protocol utilized in this study, while familiar to most regulators, is destructive in nature (i.e., monolithic structure is broken down to smaller particles), and therefore likely conservatively over estimates the amount of leaching that will occur in a full-scale application. In full-scale ISS, a large mass of contaminated soil is transformed into a low permeability soil-cement monolith that significantly retards the flow of groundwater through it, thus greatly minimizing the water contact surface area as compared to the SPLP test protocol where the soil-cement specimen is broken up into 1 centimeter or smaller as preparation for the leaching test at a pH of approximately 4.2.

Other non-destructive static leaching tests (modified from ANSI/ANS 16.1) have been utilized in at least two studies [1,22] whereby the soil-cement specimen is suspended intact in the leaching solution (site groundwater or demineralized water) for set time intervals after which the contaminant concentration in the water is measured. These tests reportedly will produce a more realistic assessment of the leaching potential of the soil-cement monolith.

Another methodology that has been used to demonstrate the acceptability of ISS at some MGP sites is the use of a contaminant transport model to predict groundwater concentrations of contaminants at a distance downgradient of the soil-cement monolith and determining the acceptable leachate concentration from the soil-cement mass [1,2,5].

5.2 Site-Specific Recommendations

Soils at all five of the sites evaluated can be solidified and stabilized, at least on some portions of each site. For areas where low strengths were achieved due to soil characteristics, the addition of more cement or the use of slag-modified cement could be evaluated to increase the strength. For any site, the feasibility of ISS from a treatment success viewpoint (i.e., contaminant immobilization) can likely be achieved at the bench-scale evaluation level. However, there are a number of considerations for any site that also factor into its implementability and costs including, but not limited to, the following:

- Presence of subsurface obstructions such as foundations, utilities, large cobbles;
- Ability to mix reagents thoroughly with clay or peat strata requires site-specific field, pilot-scale evaluation;
- Depth to contaminated strata below ground surface;
- Access restriction on third party sites related to current uses and proximity to on-going commercial and industrial activities; and,
- Potential future site uses.

5.3 Full-Scale Construction Considerations

Full-scale implementation of ISS typically requires field pilot-scale demonstration to ensure that the mix design determined in the bench-scale testing is transferable to full-scale operation. This pilot-scale demonstration often results in refinement of the mix design based on the ability to achieve mixing efficiencies and testing of cured in-situ specimens to verify that the strength, permeability, and leachate quality meets the goals set for the project. This also allows for scaling up of the mix design to correlate to the selected mixing equipment that will be used for S/S. All of the sites evaluated are underlain by several geologic strata, with contamination often impacting more than one strata. This situation lends itself best to an auger-type mixing, especially for deep soils. The physical mixing of the soils aids in the blending of the reagents with the soil, distributing the NAPL more evenly within the treatment zone for improved encapsulation, and providing a more uniform blend of the varying soil types encountered.

Inherent to the addition of S/S reagents is an increase in the soil volume. On many sites, the top several feet of soil is removed for off-site disposal so that the solidified soil volume increase can be accommodated and a clean soil cover can be placed below the anticipated surface development.

5.3.1 ISS Costs

Table 5-1 illustrates the S/S reagent cost comparison for a hypothetical site where 30,000 cubic yards of in-place soils require remediation by ISS. The unit costs for each reagent are shown as well as the cement plus reagent unit cost for the mixes evaluated in this project. For the cement/10% PAC mix which proved successful in this project, the reagent unit cost is approximately $21 per cubic yard of soil treated.

Cost data compiled by EPA [7] for S/S use at Superfund sites (including in-situ and ex-situ projects) estimated an average cost per cubic yard of $194. This data was obtained for 29 completed S/S projects. As part of this EPRI project, an ISS remediation contractor that specializes in the large diameter soil auger mixing was contacted. Their projects have typically ranged in cost from $60-$80/cy for the ISS portion of the project. Depending on how much soil removal is required to account for volume increase, costs can be upwards of $130/cy. Overall, a cost range of $80 to $200/cy would likely encompass most sites where significant ancillary construction is not required. Major cost factor include depth of mixing, reagent quantities, pre-excavation requirements, and the ease or difficulty in mixing the reagents with the soils.

Table 5-1 Solidification Reagent Cost Comparison for a Hypothetical Site

assumed volume to be treated	30,000	cy
assumed composite unit weight	1.5	tons/cy
assumed wet weight to be treated	45,000	tons
assumed water content	22	%
assumed dry weight to be treated	36,885	tons

						Reagent Unit Price					
Reagent	**Vendor**	**Product**	**Reagent Percent**	**Percent Basis**	**Reagent Weight (tons)**	**($/ton)**	**($/lb)**	**Reagent Delivered Cost**	**Material Treatment Unit Cost Per Reagent ($/cy)**	**Combined Material Treatment Unit Cost w/12% Cement ($/cy)**	**Additive/ Cement Combination**
Type I Portland Cement	La Farge Cement	Type I	12%	soil basis	4,426.23	83.50	$ 0.04	$ 369,590	$ 12.32	---	
Powdered Activated Carbon	General Carbon Corporation	GC Powdered	5%	cement basis	221.31	620.00	$ 0.31	$ 137,213	$ 4.57	$ 16.89	additive
			10%	cement basis	442.62	600.00	$ 0.30	$ 265,574	$ 8.85	$ 21.17	additive
Organophillic Clay	CETCO	PM-199	1.5%	cement basis	66.39	2,300.00	$ 1.15	$ 152,705	$ 5.09	$ 17.41	additive
			3.0%	cement basis	132.79	2,180.00	$ 1.09	$ 289,475	$ 9.65	$ 21.97	additive
Fly Ash	Brunner Island, Ohio Plant	Coal-Fired Powerplant Source	1.2%	soil basis	442.62	59.00	$ 0.03	$ 26,115	$ 0.87	$ 13.10	replacement
			2.4%	soil basis	885.25	59.00	$ 0.03	$ 52,230	$ 1.74	$ 13.71	replacement
Ground Granulated Blast Furnace Slag	La Farge Cement	NewCem	1.2%	soil basis	442.62	75.50	$ 0.04	$ 33,418	$ 1.11	$ 13.32	replacement
			2.4%	soil basis	885.25	75.50	$ 0.04	$ 66,836	$ 2.23	$ 14.10	replacement

6
REFERENCES

---

[1] EPRI, 2000. *In-Situ Solidification and Stabilization at Former MGP Sites*. Final Report 1000727.

[2] EPRI, 2003. Evaluation of the Effectiveness of *In-Situ Solidification/Stabilization at Georgia Manufactured Gas Plant (MGP) Site*. Final Report 1009095.

[3] RETEC, 2003. *Effect of In-Situ Solidification on Groundwater Quality at an MGP Site – Macon Georgia*. Presented at the June 17, 2003 EPRI MGP Forum, Denver Colorado.

[4] Portland Cement Association, 2004. *Augusta Manufactured Gas Plant Cleanup Using Cement-Based Solidification/Stabilization.* PCA website article at www.cement.org/waste/wt_apps_brown_augusta.asp.

[5] RETEC, 2002. *Completion Report, Remediation of Former Manufactured Gas Plant Exeter, New Hampshire*. Prepared for Bay State Gas/Northern Utilities, January 24, 2002.

[6] Portland Cement Association, 2002. *Solidification/Stabilization Treatment at a Former Manufactured Gas Plant Site.* SR996.

[7] EPA, 2000. *Solidification/Stabilization Use at Superfund Sites*. EPA/542/R-00/010.

[8] Portland Cement Association, 1999. *Stabilization of Heavy Metals in Portland Cement, Silica Fume/Portland Cement and Masonry Cement Matrices*. PCA RP348.

[9] Portland Cement Association, 1991. *Solidification and Stabilization of Wastes Using Portland Cement*. EB071.02.

[10] Portland Cement Association, 1997. *Guide to Improving the Effectiveness of Cement-Based Stabilization/Solidification*. EB211.01W.

[11] EPRI, 1996. *In-Situ Solidification/Stabilization of Arsenic Contaminated Soils*. EPRI TR-106700.

[12] EPA, 1986. *Prohibition on the Disposal of Bulk Liquid Hazardous Waste in Landfills – Statutory Interpretive Guidance*. OSWER directive #9487.00-2A. EPA/530-SW-86-016.

[13] EPA, 1989. *Stabilization/Solidification of CERCLA and RCRA Wastes, Physical Tests, Chemical Testing Procedures, Technology Screening, and Field Activities*. EPA/625/6-89/022.

[14] Portland Cement Association, 1979. *Design and Control of Concrete Mixtures*. EB001.12T.

[15] EPA, 1986. *Handbook for Stabilization/Solidification of Hazardous Waste*. EPA/540/2-86/001.

[16] Foster Wheeler Environmental Corporation, 2002. *Comprehensive Remedial Investigation Report, Former Hackensack Gas Works.* Prepared for Public Service Electric and Gas Company, December 2002.

[17] PSE&G, 1999. *Remedial Investigation Report, Former Harrison Gas Plane*. September 1999.

[18] PSEG SC, 2003*. Phase 4 Remedial Investigation Report, Former Market Street Gas Works*. April 2003.

[19] PSEG SC, 2003. Various draft site plans and boring logs provided to URS Corporation.

[20] Harding ESE, 2002. *Remedial Investigation Summary Report, Former Hoboken Gas Works Site*. Prepared for Public Service Electric and Gas Company, September 2002.

[21] Fernandes, et. al., 2001. *MGP Waste Stabilization Treatability Studies*, Presented at the 14th International Symposium on Site Remediation & Environmental Management in the Utility Industry, December 2001, Orlando, Florida.

[22] Lawson, et. al., 1996. *In-Situ Solidification/Stabilization Pilot Study for the Treatment of Coal Tar Contaminated Soils and River Sediments*, ASTM STP 120, Stabilization and Solidification of Hazardous, Radioactive, and Mixed Wastes, Volume 3.

[23] NJDEP, 2002. *NJDEP Standard Operating Procedures for Analytical Data Validation*. Bureau of Environmental Measurements and Quality Assurance.
5.a.15 (Revision 2 - October 31, 2001), 5.a.13 (Revision 3 - October 31, 2001),
and 5.a.16 (Revision 1 - June 17, 2002).

About EPRI

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

EPRI. Electrify the World

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case by case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

1010949

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com