New Jersey
Department of Transportation

PILOT STUDY REPORT

SEDIMENT DECONTAMINATION PILOT STUDY OF THE GEOREMEDIATION ™ PROCESS

CONTRACT NO. 9359907

NO MASS
BALANCE

Prepared for:

New Jersey Department of Transportation
(NJDOT)
Office of New Jersey Maritime Resources
(OMR)

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EXECUTIVE SUMMARY

This report presents the results of the sediment decontamination pilot study of the Georemediation™ technology conducted by BEM Systems , Inc. (BEM) under contract executed in August 2000, with the State of New Jersey, Office of Maritime Resources (OMR) [AO# 9359907]. The purpose of BEM's pilot study was to evaluate the chemical and geotechnical effectiveness of the Georemediation™ technology for the proposed beneficial use applications, and its scale-up potential for the decontamination of sediments from the New York/New Jersey (NY/NJ) Harbor. The Georemediation™ technology was selected as one of five (5) decontamination and beneficial use options presented to OMR.

Georemediation™ Technology Overview

Georemediation™ is an innovative advanced chemical treatment process that uses a proprietary reagent, a pulverized mixture of reactive basic, inorganic substrates such as fly ash, blast furnace slag, and/or cement, modified by the addition of transition metal salts, oxidants, clay pillaring agents and dispersants. The reagent is added to the contaminated sediments in a slurry form, thoroughly homogenized with the sediments, and then cured in the open. The Georemediation™ process is designed to work simultaneously on organic and inorganic (metal) contaminants. The Georemediation™ decontamination mechanism for the organic compounds involves accelerated oxidation reactions on newly formed and highly reactive surfaces. The inorganic (metal) contaminants are immobilized through pozzolanic reactions and incorporation into newly formed and insoluble crystalline structures, thereby minimizing their long-term leaching.

Pilot Study Objectives and Success Criteria

As outlined in BEM's final Pilot Study Workplan dated 03 May, 2000, BEM's pilot study objectives were to evaluate the Georemediation™ technology for its chemical effectiveness, material processing and operational effectiveness, beneficial use potential of the treated end-product, and economic and market viability of the technology at the full-scale level. In order to achieve these objectives, BEM established pilot study success criteria to determine the commercial viability of the Georemediation™ technology and potential for the beneficial use of the treated end product as structural and/or non-structural fill for the following applications: Transportation and Construction Infrastructure Projects; Brownfields Remediation and Reclamation Projects; and, Landfill Cover.

To establish the pilot study success criteria, BEM presented a detailed chemical, geotechnical, material handling, and process engineering testing program to OMR. All chemical laboratory analyses were conducted by certified analytical laboratories under direct subcontractor agreement with BEM. All geotechnical testing was performed by Soiltek, Inc., under the direct supervision of Dr. Ali Maher, Director of the Center for Advanced Infrastructure and Transportation (CAIT) Institute at Rutgers University, Piscataway, New Jersey. All material handling and process engineering related tests were either conducted by BEM or its subcontractors under executed agreements with BEM.

Source Material

The contaminated dredged material provided by OMR for BEM's pilot study was dredged from the Stratus Petroleum Site in Newark, New Jersey in November 1999. However, due to unanticipated delays in the issuance of the contracts, the material was stored in open scows for over seven (7) months, and then later re-hydrated and re-homogenized, prior to its distribution to the vendors. In July 2000, BEM received approximately 600 gallons of the re-hydrated and re-homogenized contaminated Stratus material from OMR for the pilot study.

Due to extensive storage and field re-homogenization, BEM does not consider the Stratus material to be representative of the material that may be received for decontamination at the full-scale level. Therefore, based on discussion with OMR, BEM collected approximately 200 gallons of additional dredged material from the Tremley Point location in the NY/NJ Harbor, after screening of four separate sampling locations previously identified by USEPA, using immunoassay field test kits.

Source Material Characterization Results

The results of the Stratus material characterization indicated very low levels of polyaromatic hydrocarbons (PAHs), and metal contaminants at or below the New Jersey Department of Environmental Protection (NJDEP's) "unrestricted" upland use Residential Direct Contact Soil Cleanup Criteria (RDCSCC). In addition, no pesticides or PCBs were detected in the material. However, dioxins/furans were detected at approximately 212 ppt of total Toxicity Equivalent Quotient [TEQ]. The leaching results of the Stratus material based on the NJDEP modified Multiple Extraction Procedure (MEP) indicated exceedances of arsenic (As) and lead (Pb) above the NJDEP Groundwater Quality Standards (GWQS) required by NJDEP for "unrestricted" upland use of the material.

despite this, you still found nothing

The levels of PAHs and metal contaminants detected in the Tremley Point material were similar to those detected in the Stratus material and generally below the NJDEP RDCSCC, except for arsenic, detected at a concentration of 27.6 mg/kg, above the NJDEP RDCSCC of 20 mg/kg. In addition, dioxins/furans (total TEQ) were detected at 140 ppt, above the ATSDR guidance value of 50 ppt for "unrestricted" upland use. Low levels of pesticides and PCBs were also detected in the Tremley Point material, but were below the NJDEP RDCSCC for "unrestricted" upland use.

Bench-Scale Testing

A total of five (5) separate Georemediation™ mixes (Mix 1 through Mix 5) were developed and tested at the bench-scale level at various loading rates (typically 10% and 20%) using both Stratus and Tremley Point material. The bench-scale testing was generally conducted using a bench-top blender on a 2,500 g sample of the untreated source material. The Georemediation™ mixes were added to the source material in a slurry form and well homogenized. The treated material was cured in open curing pans, and typically analyzed at the end of a 14-day curing period.

The results of the initial bench-scale testing on Stratus material using two mixes (Mix 1 and Mix 2 at 10% and 20% each) indicated a significant reduction of the dioxins/furans (total TEQ) contamination ranging from 60% to 94%. The highest percent reduction was observed for the material treated using Mix 2 at 10 % loading. The bench-scale testing results on Tremley Point material also showed the Mix 2 at 10% loading to be chemically most effective on low levels of PAHs, pesticides, and PCBs. However, both Mix 1 and Mix 2 were unsuccessful in significantly reducing the total and/or leachate concentrations of metals. Therefore, additional mixes (Mix 3, Mix 4, and Mix 5) were developed to further improve upon the chemical effectiveness of the reagents on metals. However, none of the additional mixes were successful in significantly reducing the total metal concentrations or leachate metal concentrations below the NJDEP groundwater quality standards (GWQS).

Pilot Treatment

Based on the results of the bench-scale testing, BEM selected reagent Mix 2 at 10% loading for the pilot treatment stage. The pilot treatment was conducted using the Stratus material, to simulate anticipated operational, treatment, and curing conditions that may impact the effectiveness and the economics of the Georemediation^{TM} treatment at the full-scale level. For this purpose, the following five (5) treatment and curing conditions were employed during the pilot treatment:

1. Slurried reagent addition, followed by curing at room temperature **(RT)**;
2. Slurried reagent addition, followed by curing at high relative humidity **(RH > 95%)**;
3. Slurried reagent addition, followed by curing at freezing temperatures **[FR]**;
4. Slurried reagent addition, followed by curing in deeper curing pile **[DP]**;
5. Dry powder reagent addition, followed by curing at room temperature **(DRY)**.

The pilot treatments were conducted on much larger sample batches (15-20 gallons) as compared to the bench-scale level, and homogenized with the slurried reagent using a 3 cu ft cement mixer. All treated material was cured inside the Rutgers laboratory and was not exposed to outside sunlight or wind. Treated material cured under adverse weather conditions was placed in appropriate laboratory scale equipment (e.g. custom designed humidity chamber, chest freezer, etc., deeper curing pile, etc.).

The following conclusions were drawn from the pilot treatment results:

- Highest percent reduction in the PAHs contaminants was observed for material treated using slurried reagent and cured inside the laboratory at room temperature conditions. The PAHs were reduced to below the NJDEP RDCSCC (unrestricted) upland use criteria;
- A significant improvement in the reduction of PAHs was observed after 28-day curing period, as compared to 14-day curing period. However, no significant further improvement was observed based on the results after the 62-day curing period;
- Although lower reductions in PAHs were observed during humid conditions, the freezing conditions appeared to most severely limit the reduction of the PAHs;
- The results of the treated material cured in deeper curing pan at room temperature showed a slight improvement in the PAHs reduction. This may suggest the bulking effect of the material in improving the degradation of organics;
- The addition of the Georemediation^{TM} reagent in the dry form, as compared to slurried form, appears to have a negative impact on the reduction of PAHs contaminants;
- In general the Georemediation^{TM} treatment was ineffective in significantly reducing the total metal concentrations, specifically for arsenic (As);
- The MEP leaching results show that, although, the Georemediation^{TM} treatment significantly reduced the leaching of metal contaminants, arsenic (As) and lead (Pb) still exceeded the NJDEP GWQS, applicable to "unrestricted" upland use of the material;
- The results of the dioxins/furans analysis for all pilot treatments were extremely erratic showing poor replication, and were considered largely inconclusive.

Air Emissions Testing

BEM collected grab air emissions samples during the treatment and curing of the Stratus material at the pilot level. Since the initial characterization of the Stratus material did not show any presence of volatile organics (VOCs) and very low levels of semi-volatile organics (SVOCs), very low levels of VOCs were detected during the treatment and curing of the material. Therefore, no major facility permit (Title V), or air emissions controls would be required for Stratus material. However, further air emissions testing with more contaminated and/or representative source material may be required to determine if the Georemediation™ treatment would result in unacceptable air emissions.

what about Tremley?

also — would you expect VOCs after 7 mos?

Mechanical Dewatering Test

BEM conducted mechanical dewatering tests on both the untreated source material and treated material prior to curing, in order to determine the effectiveness and advantages of using the mechanical dewatering equipment during full-scale level. The tests were performed at the laboratory scale by Komline-Sanderson using GRS-2 Kompress® Belt Filter Press technology.

The results indicated that mechanical dewatering was rather ineffective and potentially uneconomical for both untreated and treated material. In addition, the treated material passed the paint filter test (EPA method 9095) immediately after treatment, thereby showing its capacity to hold free water. This demonstrates that the curing of the Georemediation™ treated material will not result in the generation of excess wastewater runoff.

DID YOU REHYDRATE? BOTH TREMLEY + STRATUS?

Geotechnical Testing

A number of geotechnical tests were performed under the supervision of Dr. Ali Maher (Soiltek, Inc.) at the Rutgers University, CAIT laboratories, to determine the beneficial use potential of the treated material as structural and/or non-structural fill for the proposed applications.

The geotecnical tests ranged from the determination of basic geotechnical properties of the material (e.g. grain size, atterberg limits, etc.) to the strength and load bearing characteristics (e.g. California Bearing Ratio [CBR], Unconfined Compression, Resilient Modulus, etc.), and permeability characteristics. In addition, deformation characteristics under various loads and the effect of freeze/thaw were also evaluated.

The results of the geotechnical testing indicate that although the treated material may not meet the strict NJDOT and ASSHTO standards and criteria, the treated material performs equally well as compared to the materials used for subgrade material in highway applications, with controllable limitations. Some of the treated samples were, however, susceptible to the freeze-thaw effects and may require design modifications or restrictions during beneficial use without any further amendments.

The permeability values of the treated material ranged from $7x10^{-7}$ to $1.6x10^{-6}$ thereby indicating its applicability for final cover material at both brownfields sites and sanitary landfills.

Scale-Up Potential, Economic, and Market Analysis

BEM documented the scale-up potential of the Georemediation™ process for both demonstration and full-scale projects as part of its response to OMR's proposal in May 1998. Additional results of this pilot study show that some of the processes such as mechanical dewatering, water/wastewater collection and treatment, and air emissions control will likely not be required, thereby further improving the economics and scale-up potential of the technology.

The initial economic analysis presented in May 1998 documented that decontamination and beneficial use of the dredged sediments at full-scale level (i.e. 500,000 cy on annual basis) may be achieved with the Georemediation^{TM} process at $33.74 per cubic yard. The proposed modifications, based on the results of this study make it feasible to reduce the cost to $29 per cubic yard, established by OMR.

A preliminary market analysis for the proposed beneficial use applications indicates the long-term demand for the chemically and geotechnically suitable material will meet or exceed the full-scale sediment decontamination facility. Although, annual quantity projections may vary significantly, in year 2000, more than 230,000 cubic yards of non-structural and structural fill material was placed on NJDOT construction projects. In the state of New Jersey, more than $2.66 billion will be expended over the next 3-4 years under the Statewide Transportation Improvement Program (STIP) and Transportation Capital Program on transportation needs, including various state highway, and transit improvement project. The transportation projects by NJDOT and other agencies, with significant potential demands for structural and non-structural fill may provide the largest long-term market for the beneficial use of the treated dredged material. In addition, use of the treated dredged material at nominal to no material cost to the contractors will result in significant savings of $4-$6 per cubic yard to NJDOT for the typical clean borrow fill material.

how many sites meet your conditions.

but not in unrestricted sites, where most occurs.

In addition, brownfields reclamation provides a burgeoning market for the beneficial use of dredged material in the state of New Jersey, especially after the passing of the "Brownfield and Contaminated Site Remediation Act" in 1998. Current brownfields redevelopment programs by New Jersey Transportation and Planning Authority (NJTPA) in support of modern intermodal freight infrastructure development along the NY/NJ Harbor further improve the potential market for beneficial use of treated dredged material. how much?

Use of treated dredged material as daily, intermediate, and final landfill cover also presents a considerable potential market due to the presence of over 25 operational landfills in New Jersey, with over 1 million cubic yards of daily and intermediate landfill cover, and over 250,000 cubic yards of final cover placed on an annual basis. not likely, cover needs to be permeable

In conclusion, the bench and pilot scale tests did not show the chemical effectiveness of the Georemediation^{TM} technology to reduce all contaminants to levels that would allow unrestricted use for the proposed beneficial use applications. However, the geotechnical results show that the treated material may be beneficially used in several structural and non-structural fill applications with or without appropriate engineering or institutional controls generally acceptable to NJDEP. The material handling and process engineering results indicate no need for mechanical dewatering, wastewater treatment, or air emissions control, thereby suggesting at the preliminary level that the technology will likely meet the economic criteria of $29 per cubic yard at the full-scale operation. The economic viability of the technology is also supported by tremendous market potential of the Georemediation^{TM} treated end-product for the proposed beneficial use applications.

??

we don't agree

→ not necessary – it doesn't work

BEM recommends further field testing of the technology on more contaminated and representative dredged material, in order to develop the desired chemical effectiveness of the Georemediation^{TM} technology. In addition, amendments to the treated end-product and further geotechnical testing are recommended to evaluate its economic impact and improvement in the beneficial use potential.

such as?

1.0 INTRODUCTION

This report presents the results of the sediment decontamination pilot study conducted by BEM Systems, Inc. (BEM) on the sediments from the NY/NJ Harbor using the Georemediation™ process. Georemediation™ is an ex-situ soil and sediments treatment process invented and patented by the Aleph Group (formerly IWT Corp.) of Ithaca, New York, and developed and marketed exclusively by BEM for its applications to contaminated dredged sediments within the United States.

This pilot study report is a result of BEM being selected as one of the sediment decontamination technology vendors after participation in the bid solicitation (#98-X-99999) for a Sediment Decontamination Demonstration Project, issued by the State of New Jersey, Office of Maritime Resources (OMR), in March 1998. The OMR, previously known as New Jersey Maritime Resources (NJMR) and operated independently, is now formally part of the New Jersey Department of Transportation (NJDOT).

The pilot study is the first phase of a multi-staged process under OMR's program designed to validate and develop new and innovative sediment decontamination technologies. Pilot projects deemed successful by OMR will be considered for the second phase of the technology demonstration process, which involves conducting a sediment decontamination and beneficial reuse demonstration project at or near full-scale field production rates.

The source of the dredged sediments for both the pilot study and demonstration phases and/or future full-scale decontamination facilities originates from the navigable channels in the NY/NJ Harbor through maintenance dredging. The pilot study and the sediment decontamination demonstration projects are contracted by the New Jersey Department of Transportation (NJDOT), Office of Maritime Resources (OMR). These projects are funded under the Port of New Jersey Bond Act of 1996 (P.L. 1997 C.97).

The decontamination of dredged sediments, in general, is needed in cases where contaminant levels in sediment warrant reduction prior to reuse in the ocean or upland. The ultimate goal of the decontamination technology evaluation under OMR's program is to select the most cost-effective sediment decontamination technologies, which will reduce the contaminants in dredged sediments to levels which do not pose an unacceptable risk to human health and the environment while producing a beneficially reusable end-product.

The overall objectives of BEM's pilot study included the evaluation of the chemical and geotechnical effectiveness of the Georemediation™ sediment decontamination technology to produce a beneficially usable end-product; evaluation of scale-up potential of the material handling and operational processes related to the Georemediation™ technology; and economic/market analysis for the treatment and beneficial use of more than 500,000 cubic yards of sediments on an annual basis at a cost of $29 per cubic yard or less (excluding dredging cost).

The specific objectives and their success criteria for the BEM's pilot study were detailed in BEM's final Pilot Study Workplan (workplan) dated 03 May 2000. Additions and/or modifications to the original scope of work provided in the workplan were approved by OMR during the course of the pilot study operation and are presented in detail in this report.

The organization of this pilot study report is briefly summarized here. Section 3.0 presents an overview of the Georemediation™ technology. Section 4.0 summarizes the pilot study objectives and success criteria. Section 5.0 presents all methods and procedures followed during the pilot study for chemical, physical, and operational tests as part of the study. Although, some results have been discussed in Section 5.0 by reference in order to explain the basis for certain tests, all chemical, physical, and operational results are separately presented and discussed in Section 7.0. Therefore, the presentation of pilot study activities in this report may not necessarily follow the exact timeline and sequence followed during the study. However, where possible dates for various activities and tests have been provided. Section 7.0 presents a summary of the conclusions from the pilot study results and a discussion on the achievement of the pilot study success criteria. Section 8.0 presents the scale-up potential, economic projection, and market analysis for the Georemediation™ technology.

A number of photographs taken during various stages of the pilot study are included in Appendix A-1 of this report. These photographs have been incorporated into the text by reference at the end of each subsection, with a list and brief description of the photographs relevant to the discussions within that subsection.

2.0 PROJECT BACKGROUND

In October 1996, the Governors of New York and New Jersey signed a Joint Dredging Plan for the Port of New York & New Jersey. The objective of this plan is to promote greater certainty and predictability in the dredging project review process, and facilitate effective, long-term, environmentally sound management strategies for dredged material management. The goals of the plan, specific to New Jersey, include the development of technologies related to harbor sediment decontamination, control, processing, beneficial reuse, and contamination reduction and remediation. Some of the beneficial reuse options identified in the plan for continued development include upland beneficial uses such as intermediate and final landfill cover, construction material, and brownfields reclamation. The beneficial reuse applications in this plan may require decontamination, depending upon the sediment quality and regulatory requirements, prior to the beneficial use of material at the proposed locations. The plan also outlines New Jersey's commitment to develop state sponsored transportation projects (e.g. NJDOT) with the potential to utilize dredged material at an average annual volume of up to 700,000 cubic yards.

In 1997, the State of New Jersey appointed the Dredging Project Facilitation Task Force (DPFTF) under the New Jersey Commerce and Economic Growth Commission (formerly Department of Commerce and Economic Development). The DPFTF was tasked with assisting OMR in establishing priorities for dredging projects in accordance with their economic benefit to the Maritime Commerce in the State. The legislation implementing the Port of New Jersey Bond Act of 1996 required that the DPFTF review recommendations and proposals for the funding, development, and construction of disposal, treatment, or processing facilities for dredged material, decontamination and treatment technologies, dredging of navigation channels in the Port District, and dredging of navigation channels statewide.

In March 1998, as part of their charter, OMR issued a request for proposals (RFP) to seek out innovative and reliable sediment decontamination technologies capable of producing marketable end-products at a full-scale cost of no more than $29.00 per cubic yard. The target cost of $29.00 per cubic yard does not include the cost of dredging and delivery of the contaminated material to a transfer and/or treatment facility with a dock along the NY/NJ Harbor.

In May 1998, in response to this RFP, BEM developed a strategy for hosting a full-scale Central Treatment Facility (CTF) for the decontamination of sediments using the patented

Georemediation™ technology and subsequent production of beneficially reusable materials. BEM presented its strategy as part of the proposal submitted to OMR.

In November 1998, in response to OMR's bid solicitation, and based on DPFTF evaluation and recommendation, BEM was selected as one of the five vendors for the pilot study contract.

On 22 June 1999, OMR invited BEM to a pre-contract negotiation meeting, which was also attended by personnel from the United States Environmental Protection Agency (USEPA) and the New Jersey Department of Environmental Protection (NJDEP). The purpose of this meeting was to review BEM's goals and approaches to the pilot study program, and to further discuss any permitting and/or other regulatory requirements for the studies. Based on the meeting deliberations, OMR requested a revised workplan, which was prepared as the first task of the revised scope of work.

On 03 December 1999, BEM submitted a revised workplan to OMR. In addition, on 30 December 1999, BEM submitted an addendum letter to the revised workplan to OMR. This addendum letter was submitted in response to OMR's comments during a meeting and discussions that followed the submission of the revised workplan.

On 17 March 2000, BEM received OMR's final comments to the revised workplan. On 03 May 2000, BEM submitted the final workplan, incorporating responses to OMR's comments. The initial scope of work established in the workplan was based on the guidance and input provided by OMR, NJDEP and USEPA at the pre-contract negotiation meeting and through subsequent comments and discussions with OMR.

On 28 March 2000, BEM received the draft Terms and Conditions of the contract for the Sediment Decontamination Pilot Project of the Georemediation™ technology from OMR. On 03 May 2000, BEM submitted its comments to the draft contract in a letter to OMR. On 12 June 2000, OMR sent a final copy of the contract to BEM through email. On 03 July 2000, BEM submitted three duly signed copies of the final contract along with the completed and signed copies of the requested forms and insurance certificates as part of the terms and conditions of the contract.

On 18 August 2000, BEM received a fully executed contract with OMR under the Sediment Decontamination Technologies Program with the Agency Order (AO#) 9359907.

3.0 GEOREMEDIATION™ TECHNOLOGY AND PROCESS OVERVIEW

A general overview of the Georemediation™ decontamination mechanisms and treatment process was previously presented in BEM's final workplan dated 03 May 2000. A brief overview of the technology and treatment process is represented here prior to the discussion of the pilot study objectives and presentation of the pilot study results.

Georemediation™ treatment process uses a proprietary reagent, which is a pulverized mixture of reactive, basic, inorganic substrates including fly ash, blast furnace slag, and/or cement, modified by the addition of transition metal salts, oxidants, clay pillaring agents and dispersants. The treatment process involves the initial mixing of the proprietary reagent with water to create a slurry, using 1:1 reagent to water ratio. The slurry is then mixed with the contaminated material using simple "off-the-shelf" equipment such as pug mill. Typically, proprietary reagent is added at 10-15% loading, by weight of the contaminated material. Georemediation™ process benefits from the natural moisture content of the material for pozzolanic reactions, with no excess free liquids typically produced during decontamination process, even in the case of 50% solids dredged material. The homogenized material-reagent mixture is then allowed to cure in the open for a period of 15 to 30 days, after which the decontaminated material may be beneficially reused. The mixing and curing processes are anticipated to minimize the need for any wastewater discharge permits and/or management of unwanted by-products.

Georemediation™ decontamination process is designed to work on wastes contaminated with both organic and inorganic (metal) contaminants. In general, the Georemediation™ decontamination process for organic contaminants can be described in the following nine stages, some of which might take place concurrently, others sequentially:

1. The basic reagents (fly ash, blast furnace slag, or cement, etc.) generate colloidal or proto-smectitic clay (and some times zeolitic phases) which has a large surface area and properties that allow the adsorption of added (proprietary) transition metal cations which then have the ability to act as electron receptors.
2. The surface area of the smectite may be enhanced through addition of dispersants and/or molecular pillaring agents such as alkylammonium ions, thus facilitating step 3.
3. The organic compounds are adsorbed on the surfaces of the colloidal smectite.
4. Transition metal oxides, such as those of iron or manganese which result from the precipitated excess of Fe^{2+} or Mn^{2+} upon oxidation and hydrolysis of the added Fe^{2+} or Mn^{2+} salts, coat mineral surfaces and occupy exchange sites of the smectites.
5. Bond breaking of the organic compounds and formation of free radicals is facilitated by prior adsorption on the smectite surface. Reactivity is enhanced by the constraints of reactions taking place on two-dimensional surfaces rather than in the bulk aqueous phase.
6. Oxidative reactions involving adsorbed organic compounds and their free radicals are likely catalyzed by transition metals occupying exchange and/or structural sites of the clay colloids, with contaminant reduction of transition metals.
7. Oxygen or supplied aggressive oxidants re-oxidize the reduced transition metal cations in the smectites and in coatings on mineral surfaces.
8. Exothermic heating, due to the oxidation of the organic compounds, accelerates oxidation of the remaining organic compounds.

9. The volatile oxidation products of the organic compounds (i.e., CO_2, H_2O, HCl, etc.) are likely fixed by reaction with calcium in the altering fly ash, slag and cement. Consequently, little or no release of gaseous compounds is expected.

The Georemediation™ decontamination mechanism for inorganic (metal) contaminants generally involves their immobilization through pozzolanic reactions and incorporation into newly formed and insoluble crystalline structures. These crystalline structures significantly reduce any potential for leaching, and in some cases may reduce the total metal concentrations detected through acid digestion tests (SW846 3050B/6010B).

4.0 PILOT STUDY OBJECTIVES AND SUCCESS CRITERIA

This section presents BEM's pilot study objectives and criteria established to evaluate the success in meeting the overall objectives of OMR's sediment decontamination program.

4.1 Pilot Objectives

The principal objectives of the pilot study were to evaluate the decontamination efficacy, beneficial use potential, and material processing throughput that could be achieved at the desired economics with the Georemediation™ process.

The following summarizes the specific pilot study objectives, previously outlined in BEM's final workplan dated 03 May 2000:

Sediment Decontamination Efficacy

- Evaluate the Georemediation™ reagent mix formulation (type) and reagent loading rate to provide the most appropriate degree of decontamination efficacy during pilot scale treatment of the dredged material; FAILED
- Evaluate the curing periods to provide the most appropriate degree of decontamination for the treated material for the applicable anticipated beneficial reuse applications; FAILED
- Validate the chemical effectiveness of the selected Georemediation™ reagent loading rate to reduce and/or stabilize the contaminants in the dredged material to levels acceptable for the anticipated reuse applications. FAILED

Material Processing and Operational Issues

- Evaluate the potential for the release of unacceptable levels of air emissions during decontamination treatment reactions and curing processes; NOT APP.
- Validate the efficacy of the decontamination process under varying environmental conditions similar to reasonably anticipated adverse weather conditions (cold and humid curing conditions); ACHIEVED
- Determine the potential effect of curing bed depth upon the decontamination process in order to anticipate requirements for full-scale design; ACHIEVED
- Investigate the efficacy of mechanical dewatering equipment in reducing the moisture content of the dredged material prior to and after the reagent mixing, and identify any effects on the chemical efficacy of the sediment decontamination; ?
- Analyze the chemical quality of the pore-water obtained from the mechanical dewatering study for both the untreated and treated dredged sediment and determine the efficacy of the ?

treatment process to decontaminate the sediment pore-water. This will also provide BEM with the design parameters for the potential pore-water treatment, if deemed necessary.

Anticipated Beneficial Use Applications

- Evaluate geotechnical properties of the decontaminated material using existing industry standards and criteria to assess its suitability for specified beneficial use applications;
- Demonstrate that use of material treated with Georemediation™ does not cause an unacceptable risk to human health by comparing contaminant levels against existing NJDEP Residential- and Non-Residential Direct Contact Soil Cleanup Criteria (RDCSCC and NRDCSCC) and testing methodologies as specifically requested by OMR and in a manner consistent with the October 1997 NJDEP Technical Manual, "The Management and Regulation of Dredging Activities and Dredged Material in New Jersey's Tidal Waters" (NJDEP Technical Manual). FAILED

Economic Projection and Market Analysis

- COST Demonstrate, based on economic analysis, that the projected unit cost ($/cubic yard) for the decontamination and beneficial reuse of sediments treated with Georemediation™ at demonstration project level (30,000 to 120,000 cubic yards) and full-scale levels (500,000+ cubic yards annually) will meet the goal of $29/cubic yard or less that was established by NJDOT and OMR;
- MARKET Demonstrate the economic viability of the selected beneficial reuse applications through a market analysis for both the demonstration project and full-scale implementation of the technology. NO NUMBERS

4.2 Pilot Study Success Criteria

The success of BEM's pilot study will be evaluated by OMR based on the overall objectives of the sediment decontamination program. These objectives include the capability of the Georemediation™ process to produce an environmentally and geotechnically acceptable end-product at the desired capacity of 0.5 to 1-million cubic yards annually at a unit cost of $29/cubic yard or less at the full-scale level.

The pilot study success criteria for the Georemediation™ process hinge on the anticipated beneficial use applications, market availability, and demands for the treated material. As part of this report, Georemediation™ treated end-product will be evaluated for the following beneficial use applications:

- **Transportation and Infrastructure Construction Projects** – End-product used as construction fill material for structural applications such as railroad/roadway sub-base and sub-grade material, embankment fill material, and containment dike fill material, and non-structural applications such as general fill material;
- **Brownfields Remediation and Reclamation Projects** – End-product used as backfill material for non-remedial construction, and capping material for the reclamation, remediation and redevelopment of abandoned brownfield sites;
- **Landfill Cover** – End-product used as daily, intermediate, or final cover material for sanitary municipal landfills.

As per the October 1997 NJDEP document "The Management and Regulation of Dredging Activities and Dredged Material in New Jersey's Tidal Waters" (Technical Manual), a contractor is required to obtain an Acceptable Use Determination (AUD) from the NJDEP prior to any beneficial upland use of the amended dredged material. Therefore, the success criteria detailed in this report are established to facilitate the approval of an AUD application for the Georemediation$^{\text{TM}}$ treated end-product.

The success criteria for the specific pilot study objectives outlined in Section 4.1 are described as follows:

4.2.1 Sediment Decontamination Efficacy Success Criteria

The success criteria for the pilot objectives of the sediment decontamination rely on the compliance of the end-product with the environmental standards and regulatory criteria for the anticipated beneficial use applications, based on the human health risk and impact to groundwater quality. The success criteria against any ecological risk from the use of the decontaminated sediments will not be addressed in this report, based on OMR's request to omit any ecological testing during this study.

As per the October 1997 NJDEP Technical Manual, assuming the end-product meets the necessary physical and engineering specifications for the beneficial use applications previously stated, NJDEP's main concerns are:

- Potential human exposure to contaminants in the dredged material; and
- The dispersal of contaminants from the amended dredged material, especially the leaching of contaminants due to percolation and stormwater run-off.

Currently, NJDEP evaluates the beneficial use of the end-product on a case-by-case basis, which is in accordance with the AUD process. The analytical testing requirements for the beneficial use applications identified in this pilot study report are presented in Appendix B of the NJDEP Technical Manual and include the following:

- Bulk Sediment Chemistry;
- Leaching Test (Multiple Extraction Procedure [MEP]).

The results of the above analyses will be compared to the human-health and groundwater quality standards and criteria (except for dioxins/furans) established by NJDEP. These standards were presented in Section 6.0 of BEM's 03 May 2000 workplan, and are described below:

- NJDEP Residential Direct Contact Soil Cleanup Criteria (RDCSCC) for bulk sediment chemistry analysis (except dioxins/furans); → FAILED
- NJDEP Groundwater Quality Standards (GWQS) for the MEP leachate analysis. → FAILED

If the end product contaminant levels are below the most stringent upland criteria presented in Appendix A of the NJDEP Technical Manual, the material may be beneficially used without any restrictions, provided it meets the physical and engineering specifications required for the selected beneficial use applications.

For sediments contaminated with volatile organic compounds (VOCs), the most stringent criteria is generally NJDEP Impact to Groundwater Soil Cleanup Criteria (IGWSCC), as opposed to the RDCSCC. However, the levels of VOCs in most dredged material from navigable channels are generally low and are not anticipated to reach concentrations above the regulatory levels in the amended end-product.

For sediments with dioxin contamination, no NJDEP soil cleanup criteria or guidance levels are currently available. However, in 1997, the Agency for Toxic Substances and Disease Registry (ATSDR), U.S. Department of Human Health & Services published the Interim Policy Guidelines for "Dioxin and Dioxin-Like Compounds in Soil, Part 1" document. Based on the guidelines presented in this document, the unrestricted use of an end-product, without the need for any risk evaluation, would require toxicity levels at or below the Screening Level of 50 ppt (0.05 ppb) for the total dioxin Toxicity Equivalent Quotient (TEQ).

remove

In December 1999, USEPA proposed to prohibit the land application of the sludge with dioxin concentrations exceeding 300 ppt. The USEPA is under court order to issue this rule by 15 December 2001. The so-called Part 503 Sewage Sludge Use rule under the Clean Water Act will also contain monitoring and record-keeping requirements. The USEPA may, however, use a revised risk assessment of the dioxin exposure in the final rule, based on a probabilistic approach rather than a deterministic approach whereby single values are plugged into a model. Since the final values from the EPA are not yet available, BEM will compare the total TEQ data for dioxins/furans with the 50 ppt, previously suggested by ATSDR.

remove

End-product with contamination above the unrestricted use criteria discussed above may still be used in several aforementioned beneficial use applications, provided certain institutional and/or engineering controls acceptable to the governing regulatory agencies and the public at large are adopted. However, these restrictions may severely limit the marketability of the end-product. The following provides a brief description of the controls generally required by NJDEP for the beneficial use of a material with contamination levels above RDCSCC criteria:

- "Institutional Controls" require the filing of a "Deed Notice" with the deed of the property prior to its transfer of ownership, and may prohibit the alteration, improvement and development of the property, without notification to or permission from the regulatory agency, in order to protect the human health. Institutional controls are generally placed when contamination on the property exceeds the most stringent regulatory cleanup criteria (e.g. NJDEP RDCSCC developed based on human health risk);
- "Engineering Controls" are generally required by NJDEP, in addition to the placement of institutional controls, on a property with contamination that, without such controls, poses a considerable threat to human health or to the environment. Engineering controls may include placement of impermeable cap on the contaminated material, removal of contaminated material from the saturated zone, and removal of material up to two (2) feet above the groundwater table, etc.

Although, the overall success of the decontamination efficacy will be evaluated against the unrestricted use criteria, less stringent success criteria, which are acceptable to NJDEP when institutional and/or engineering controls are in place, are summarized in Table 4-1.

Table 4-1: Sediment Decontamination Efficacy Success Criteria

Beneficial Use Restrictions[a]	Test Parameters	Applicable Success Criteria[b]	Beneficial Use Examples
Unrestricted Use	Bulk Sediment Chemistry	RDCSCC	- Fill material for most transportation and infrastructure construction (provided geotechnical criteria are met) ?
	Dioxins/Furans	TEQ 50 ppt	
	Leachate (MEP)	GWQS	
Institutional Controls (e.g. Deed Notice)	Bulk Sediment Chemistry	> RDCSCC, NRDCSCC or IGWSCC (as applicable)	- Fill material for selected transportation and infrastructure construction, typically in industrial areas (provided geotechnical criteria are met) ?
	Dioxins/Furans	TEQ 50 ppt	
	Leachate (MEP)	GWQS	
Institutional/ Engineering Controls (e.g. Deed Notice / Impermeable Cover, etc.)	Bulk Sediment Chemistry	> NRDCSCC or IGWSCC (as appropriate) Site-Specific Criteria	- Fill material used for brownfields redevelopment (using proper controls); - Cover material for landfills ?
	Dioxins/Furans	TEQ > 50 ppt, 1 ppb	
	Leachate (MEP)	GWQS	

[a] Restrictions and success criteria identified are based on NJDEP regulations for upland placement of material in the state of New Jersey (except for dioxins/furans)

[b] RDCSCC: NJDEP Residential Direct Contact soil cleanup criteria; NRDCSCC: NJDEP Non-Residential Direct Contact soil cleanup criteria; IGWSCC: NJDEP Impact to Groundwater soil cleanup criteria; GWQS: NJDEP Groundwater Quality Standards.

4.2.2 Material Processing and Operational Success Criteria

The Georemediation™ process is simple when compared to the application of other innovative sediment decontamination technologies. The process has basic engineering operations that utilize off-the-shelf equipment. Although, the application of the Georemediation™ reagent achieves the advanced chemical treatment of contaminated sediments, the underlying operational processes have been widely used for typical solidification/stabilization (S/S) processes.

not shown

The following presents the success criteria for the evaluation of some of the key operational aspects of the Georemediation™ process:

4.2.2.1 Air Emissions Control Requirements

As per the New Jersey air permit requirements under N.J.A.C. 7:27-8, "Permits and Certificates for Minor Facilities", any facility handling more than fifty (50) pounds of raw material per hour must have an air permit. Therefore, at the demonstration and/or full-scale levels, a minor facility air permit will be required for the Georemeidation™ treatment facility.

Regardless, the Georemediation™ treatment and curing processes will be monitored for air emissions to ensure that additional regulatory permits for the treatment facility would not be required. The objective of this monitoring is to utilize analytical results to demonstrate that Georemediation™ process does not generate unacceptable levels of air pollutants.

The results of the air emissions monitoring will be compared to Major Facility emission thresholds and the state-of-the-art (SOTA) thresholds published in N.J.A.C. 7:27-8. Any exceedance of the Major Facility emissions thresholds would trigger the requirement of a Title V air permit. If the Georemediation™ treatment facility emissions exceed the state-of-the-art (SOTA) thresholds, a SOTA technology would have to be implemented in order to reduce emissions sufficiently to comply with the SOTA thresholds. Based on BEM's understanding of the Georemediation™ treatment process and previous contaminant levels found in the sediments dredged from the navigable waterways of the NY/NJ Harbor, it is not expected that air emissions will require a Title V air permit or trigger the SOTA thresholds.

Table 4-2 presents the limits of Major Facility, for which any exceedance would trigger a Title V air permit requirement, and the state-of-the-art thresholds, for which any exceedance would require the implementation of a SOTA technology.

Table 4-2: Major Facility and State-of-the-Art Thresholds N.J.A.C. 7:27-8

Air Contaminant	Major Facility Threshold (tons/year)	State-of-the-Art Threshold (tons/year)
Total Volatile Organic Carbon (VOC)	25	5
Total Suspended Particulates (TSP)	100	5
Particulate Matter –10μm (PM-10)	100	5
Nitrogen Oxides (NO_x)	25	5
Carbon Monoxide (CO)	100	5
Sulfur Dioxide (SO_2)	100	5
Lead (Pb)	10	.01
Any Hazardous Air Pollutants (HAPs)[a]	10	See N.J.A.C.7:27-8 Table B
All Hazardous Air Pollutants (HAPs)[a]	25	See N.J.A.C.7:27-8 Table B
Any other air contaminant	100	Not Applicable

[a] List of Hazardous Air Pollutants is provided in N.J.A.C 7:27-8 Appendix B. Many of the VOCs, SVOCs, and metals tested by BEM qualify as HAPs. All of the PCBs (Aroclors) tested qualify as HAPs.

4.2.2.2 Decontamination Under Adverse Weather Conditions

This pilot study is also designed to provide preliminary evaluation of the effect of adverse weather conditions on the decontamination efficacy of the Georemediation™ treatment during material curing in open beds. It is anticipated, however, that a full-scale sediment decontamination facility would likely not be operational all year round. The operations may likely coincide with the maintenance dredging schedule and channel deepening activities within NY/NJ Harbor. Based on the uncertainty of the maintenance dredging schedule, it is important to evaluate whether decontamination mechanisms would be negatively impacted during curing due to adverse weather conditions (e.g. rain, snow, etc.). For this purpose, the following weather conditions were considered:

- High Relative Humidity (R.H. > 95%);
- Freezing Conditions (Temp. 32° F).

The success criteria for curing under these conditions will be the same as previously listed in Table 4-1. In addition, the results will be compared with the treatment results from the optimum curing conditions, as determined during the study.

The effects of the adverse weather conditions on the decontamination efficacy will be considered minimal, provided the following criteria are met:

- Compliance of the end-product with the aforementioned beneficial use applications' environmental standards and regulatory criteria;
- The relative standard deviation (R.S.D.) or relative percent difference (RPD) of < 20% between the results under adverse weather conditions and the optimum treatment conditions evaluated during the pilot study.

Although, the adverse weather conditions may not severely affect the chemical efficacy, the geotechnical suitability of the treated end-product may require that an optimum moisture content be achieved. Therefore, it is also important to gauge the impact of the adverse weather conditions on the length of the curing period that would be required in order to achieve the optimum moisture content.

4.2.2.3 Depth of Curing Piles

Following the Georemediation™ treatment, the newly amended dredged material will be cured in open curing piles for several weeks prior to their beneficial use. The land requirements for the curing piles will have a direct impact on the facility and operational costs of the Georemediation™ treatment facility. These costs will be lowered if curing could occur in deeper piles without any adverse impact on the decontamination efficacy. The impact of the deeper curing piles on the decontamination efficacy will be considered minimal, provided the following criteria are met:

- Compliance of the end-product with the aforementioned beneficial use applications' environmental standards and regulatory criteria;
- The relative standard deviation (R.S.D.) or relative percent difference (RPD) of <20% between the results under deeper curing piles (e.g. three [3] times deeper) and the optimum treatment conditions determined during the pilot study.

which

4.2.2.4 Mechanical Dewatering/Wastewater Treatment Requirements

Prior to mixing with the contaminated sediments, the Georemediation™ reagent is slurried using an equal amount (by weight) of water. Since dredged material generally has high moisture content (45%-65%) compared to contaminated soils, the potential for excess free water during the curing of the treated sediments material must be evaluated.

If it is determined that the Georemediation™ amended dredged material produces excess free water due to low initial percent solids, a mechanical dewatering or other leachate collection system may be required prior to or during the curing process. The need for mechanical dewatering prior to or after Georemediation^{TM} treatment may significantly increase the operational and treatment cost at the full-scale level. In addition, potential on-site or off-site treatment of the wastewater generated during mechanical dewatering would increase the cost of treatment.

As part of the pilot study, the need for the mechanical dewatering and wastewater treatment will be evaluated. Should such operations be warranted, an economic analysis will be conducted to determine the advantages and disadvantages of mechanical dewatering/wastewater treatment. It is important to evaluate the economic viability for these operations as the success will depend upon the treatment process meeting the cost criteria of $29/cy for the treatment and beneficial use of the material at full-scale level.

4.2.3 Beneficial Use Success Criteria

One of the conditional factors for success of the Georemediation^{TM} process depends upon the geotechnical suitability and market potential of the decontaminated end-product for the anticipated beneficial use applications discussed in Section 4.2. The decontaminated end-product may be used as a non-structural or structural fill as part of the anticipated beneficial use applications. The criteria for various structural fill applications differ from non-structural fill applications in that certain specific load bearing requirements must be met for structural fill.

Existing geotechnical standards and criteria, established by agencies such as NJDOT and American Association of State Highway and Testing Officials (AASHTO), are largely based on grain size distribution. The grain size distribution for the majority of the dredged material falls outside of these geotechnical standards and criteria due to the large proportion [50% to 95%] of fine material that passes through a 75-micrometer sieve. Nonetheless, the soils that achieve compliance with the grain size distribution based standards and criteria are expected to deliver the geotechnical performance required for a specific application. The equivalent geotechnical performance of the dredged material may not be readily discernible when it is solely based on grain size distribution. Therefore, a performance-based geotechnical evaluation of the amended dredged material is necessary to demonstrate its potential suitability for the proposed beneficial use applications. To this end, OMR is acting in collaboration with the Rutgers University, Center for Advanced Infrastructure and Transportation (CAIT) Institute to test the geotechnical performance of dredged material, treated with various reagent mix types, for several upland beneficial use applications. The results from these studies may eventually be used in developing performance- based standards and criteria for the use of amended dredged material in structural and non-structural fill applications.

Existing geotechnical standards and performance criteria that will be used to evaluate the geotechnical success of the Georemediation^{TM} treated dredged material are discussed in the following section.

4.2.3.1 Transportation and Infrastructure Construction Projects

As outlined in the 1996 Joint Dredging Plan for the Ports of NY & NJ, the State of New Jersey is committed to developing a State sponsored transportation project with agencies such as NJDOT, that will utilize dredged material in volumes of up to 700,000 cubic yards each year. The dredged sediments may be used for structural and non-structural fill applications, which would require more elaborate testing in order to achieve performance equivalent to the soil-like material which has traditionally been used for such applications.

I. NJDOT Criteria

The present specifications used by NJDOT for structural and non-structural fill material were developed based on NJDOT experience and major research efforts sponsored by AASHTO in the 1950s. These approaches led to the establishment of simple grain size distribution requirements, that predicted the performance of the soil as embankment fill (Zones 1, 2, and 3). Zone 1 and Zone 2 embankment fill material designations are generally limited to sand blanket and coarser soil aggregate material placed on swamps, marshes, and other unstable grounds. Zone 3, in swamp embankments is the embankment above Zone 2, which also includes all other areas of embankment constructed on firm ground. The 1996 NJDOT Standard Specifications for Road and Bridge Construction specify the gradation designation of the material classified as Zone 3 embankment material as follows:

- The portion of the material passing the 100-millimeter sieve (4-inch sieve) shall contain no more than 35 percent, by weight, of material passing the 75-micrometer sieve (No.200 sieve).

There are no other test requirements in the NJDOT specifications for the material used as Zone 3 embankment fill or material used as sub-grade and sub-base for road and bridge construction projects. These specifications were originally developed for material composed of soil aggregate or soil aggregate and rock. Generally, dredged sediments do not meet these gradation-based NJDOT specifications. This is due to the assumption that materials that possess suitable gradation characteristics will possess acceptable strength, bearing capacity, corrosion resistance, and freeze-thaw index. Furthermore, no specific standards exist for the fill material used as sub-grade or sub-base, since it may vary significantly depending upon the anticipated loads and the strength characteristics of the material.

Although there are no general guidelines, criteria, or standards for the geotechnical evaluation of dredged material, the following geotechnical parameters are valuable in assessing material use potentials:

- Bearing Capacity (California Bearing Ratio [CBR] and Resilient Modulus Test) [ASTM D1883 and AASHTO T274];
- Strength characteristics (Unconfined Compressive Strength, UC) [ASTM D2166];
- Compaction characteristics for use as sub-base and sub-grade fill material for roadways (Modified Compaction Test) [ASTM D1557ff 180];
- Deformation characteristics (Freezing and Thawing Test) [ASTM D560];
- Corrosion characteristics (Sulfates, Chlorides and Resistivity) [ASTM D516 and ASTM 512];
- Permeability [ASTM D5084].

A description of each of these standard tests and their applicability with respect to the beneficial use of dredged materials is provided as follows:

II. Bearing Strength Characteristics

One of the important characteristics of structural fill material is the need for strength and load bearing capacity. These characteristics are measured using the Unconfined Compressive Strength Test and the California Bearing Ratio (CBR) Test. The bearing strength characteristics of a material are largely dependent on the dry density and the moisture content of the material.

Typically, the required bearing strength of material used for construction applications may have CBR values ranging from 10 to 90 (unconfined compressive strength of 14 to 130 psi) or more, depending upon the type of application (non-structural or structural fill*)*. Table 4-3 provides some of the typical ranges of CBR values for materials generally used as structural and non-structural fill in flexible pavement designs in roadway construction projects (as published by Portland Cement Association [PCA]).

Table 4-3: Typical Ranges of CBR Values for Roadway Applications

California Bearing Ratio (CBR)	Typical Roadway Applications
70-90	Highest quality base course
40-70	Suitable quality base course or sub-base material depending on pavement design and sub-grade condition
20-40	Suitable quality sub-base material
10-20	Sub-grade or select material

With the gradual shift to "Mechanistic Pavement Design" methods by AASHTO, the State transportation agencies have been specifying the use of resilient modulus testing for the evaluation of materials to be used in road base and sub-base materials. Unlike static CBR tests, resilient modulus tests simulate cyclic loading on sub-grade soils, which is important in analyzing soil deformation under dynamic vehicular loads. The bearing strength of soils and sediments can be greatly enhanced by compacting the material and using additives such as cement and lime. The Georemediation^{TM} decontamination process enhances the strength characteristics of the material due to the presence of pozzolanic material such as cement and/or slag in the treatment reagent, in addition to oxidants, salts, and dispersants.

III. Compaction Characteristics

The compaction characteristics of a material is very important in evaluating its potential use as structural fill material since these characteristics control the bearing strength of the material. In transportation and construction applications, fill is typically placed in 6 to 12-inch lifts and compacted with an acceptable compactive energy input, based on the anticipated loads. The compaction test measures the relationship between soil density and moisture content for a standardized compactive energy input, which dictates the moisture related condition of soil materials prior to their use as structural fill. The decontaminated dredged material may be compacted to Maximum Modified Density (MMD) to evaluate its strength and CBR values. The density of the soil material typically used in fill applications ranges from 130 to 160 pounds/cubic foot (pcf) at optimum moisture contents ranging from 15 to 25%.

IV. Deformation Characteristics

Deformation characteristics relating to the moisture content and freezing temperatures are important for the material used in construction fill applications. These characteristics are measured by the swelling potential, and the freeze-thaw performance of the material during its use.

Swelling and expansion index tests may be performed to obtain values of percent swelling, swelling pressure and expansion index. These values provide insight to the performance of the material during cyclic fluctuation of groundwater table. Typically a percent swelling value of greater than 4 (roughly corresponding to a plasticity index of 20) is an approximate borderline between expansive soils and less expansive soils which would perform better. Similarly, swell pressures greater than 0.6 tons/square foot (tsf), may prove to be unacceptable for certain applications. The expansion index for soil typically suitable for fill applications may range from 5 to 7, depending upon the compaction levels of the material.

Freeze-thaw testing evaluates the number of cycles or freezes and thaw sustained by a sample and its change in volume prior to failure. The results of such testing can be used to evaluate the placement of treated material with respect to the frost line or insulating the material from adverse weather conditions in a construction setting. The number of freeze-thaw cycles sustained by soil material typically used in fill applications, ranges from 2 to 5 cycles, depending upon the compaction levels of the soil.

4.2.3.2 Brownfields Remediation and Reclamation Projects

The applicable geotechnical parameters used to evaluate the potential use of decontaminated dredged sediments as general backfill material for remedial and non-remedial construction at brownfields sites, include the following:

- Strength characteristics (UC and Triaxial Test) for slope stability and shear strength, etc.;
- Permeability for reuse as capping material.

There are no existing standards or criteria relating to the bearing capacity for the reuse of dredged material as general backfill. The actual standards for a specific application depend upon the anticipated loads and expected performance. Anticipated loads can vary from close to zero (at or near the surface as cover material) to high loads (material placed on extreme slopes or under heavy structures with large loads).

The permeability of materials, used as cover to prevent dermal exposure or as backfill, is generally not specified. However, permeability of approximately 10^{-7} cm/sec may be required for final cover, which cuts off or reduces infiltration to the groundwater. Both applications occur on brownfield sites, and therefore the permeability will be evaluated under this beneficial use option.

also contains! must be specified in RAWP

4.2.3.3 Landfill Cover

The decontaminated sediments may potentially be used as daily, intermediate or final cover material for various sanitary landfills operational in the State of New Jersey. As an alternative material, other than clean soil, the use of decontaminated sediments for landfill cover applications will require NJDEP's approval, provided the following criteria are met:

- The material impedes the entry of rodents and vectors into the waste fill;

- The material controls malodorous emissions;
- The material provides a firebreak;
- The material resists or has limited erosion potential and is not easily windblown; and
- The material controls windblown litter.

In general, heavy clays and very fine grain materials, such as fly ash, are not allowed to be used as daily and intermediate cover due to their poor workability and potential for generating windblown dust. Since decontaminated sediments are expected to be relatively fine-grained, their use as daily and intermediate landfill cover may be limited, and may largely depend upon the source material characteristics. The following geotechnical tests are generally required by NJDEP, Division of Solid and Hazardous Waste (DSHW) [N.J.A.C. 7:26, Subchapter 2A] for daily or intermediate landfill cover:

- Solids content;
- Percent volatile solids;
- Grain size analyses; and
- Moisture content.

The material used for daily and intermediate landfill cover is generally required to meet the following standards:

- The volatile solids, or combustible content of the cover shall not exceed 12 percent by weight;
- No more than 20% of fine-grained materials shall pass a No. 200 sieve;
- At least 40 percent by weight of the fragments in the material shall be capable of passing through a No. 10 mesh sieve; and
- Particle sizes shall not exceed six inches in diameter.

For the material used for final or temporary final cover, NJDEP, DSHW requires the following additional geotechnical tests:

- Atterberg limits; and
- Permeability testing.

The key requirement for the final cover material is its permeability, which should be less than or equal to the bottom liner system or natural subsoils present underneath the sanitary landfills. Typically, permeability values of 1×10^{-5} cm/sec or less are desirable for final cover material. The moisture content of the material during compaction plays an important role in achieving the desired permeability of the material. Typically the capping material is compacted under slightly moister conditions that the optimum, thereby lubricating and allowing the particles to disperse more and produce a less flocculated and less permeable compacted soil.

In addition, the strength characteristics of the final cover material may be important for the placement on slopes and equipment loading during landfill operations. These characteristics can be established by measuring shear strength, cohesion, and angle of internal friction of the material. Typical slopes used in landfill applications may be as steep as 3:1 (Horizontal:Vertical).

4.2.4 Economic Projection and Market Analysis

The economic viability of the Georemediation^{TM} process, at or near the full-scale level, depends upon the following financial success criteria, as determined by OMR under its sediment decontamination program:

- The ability to decontaminate and beneficially use approximately 500,000 to 1,000,000 cubic yards of contaminated sediments from NY/NJ Harbor on an annual basis for less than $29 per cubic yard, excluding the cost of dredging and delivery of the sediments to a waterfront-based treatment facility;
- Demonstration of the viability of the beneficial use of all of the annually treated end-product using a combined market analysis for the selected beneficial use applications. This market viability component presumes that the general public will be receptive to the use of the treated material in the areas and for the types of applications proposed.

5.0 METHODS AND PROCEDURES

This section presents the procedures and methodologies followed during various stages of the pilot study. Several changes or additions to the initial scope of work, presented in the final workplan dated 03 May 2000, were made during the pilot study based on the unanticipated developments concerning the nature of the untreated material, and the results of the bench-scale tests. Although, some of these results are briefly referenced in this section to explain to basis for such changes or additions, the complete pilot study results and related discussions are presented separately in Section 6.0. All standard procedures or tests used have been appropriately referenced.

5.1 Facility Set-up/Operations

All pilot operations in this study were conducted at a dedicated laboratory space at the Rutgers University, Center for Advanced Infrastructure and Transportation (CAIT) Research Institute, located at Building 4109, Road 1, Piscataway, New Jersey. The facility was made available to BEM under a letter of commitment dated 27 December 1999 by Dr. Ali Maher, Chairman of the Department of Civil Engineering, and CAIT Research Institute at Rutgers University.

A general layout of the pilot facility at the Rutgers/CAIT building, where all of the pilot operations were conducted, is presented in Figure 5-1. The general features, facilities, and amenities available at the facility are described below:

- The laboratory space dedicated to the pilot study project (pilot facility) is a 30'x24' area at the Geotechnical and Beneficial Reuse Laboratories at the Rutgers/CAIT facility;
- A garage door along the backwall of the pilot facility opens to the outside rear of the CAIT laboratories with limited to no automobile access;
- The pilot facility is equipped with a laboratory exhaust hood with an average exhaust rate of 150 fpm;
- A sink with a continuous cold tap water supply is available inside the pilot facility.

As previously presented in BEM's Health and Safety Plan (HASP), modified in response to OMR's comments and concerns, and submitted in May 2001, the laboratory was divided into the following work zones:

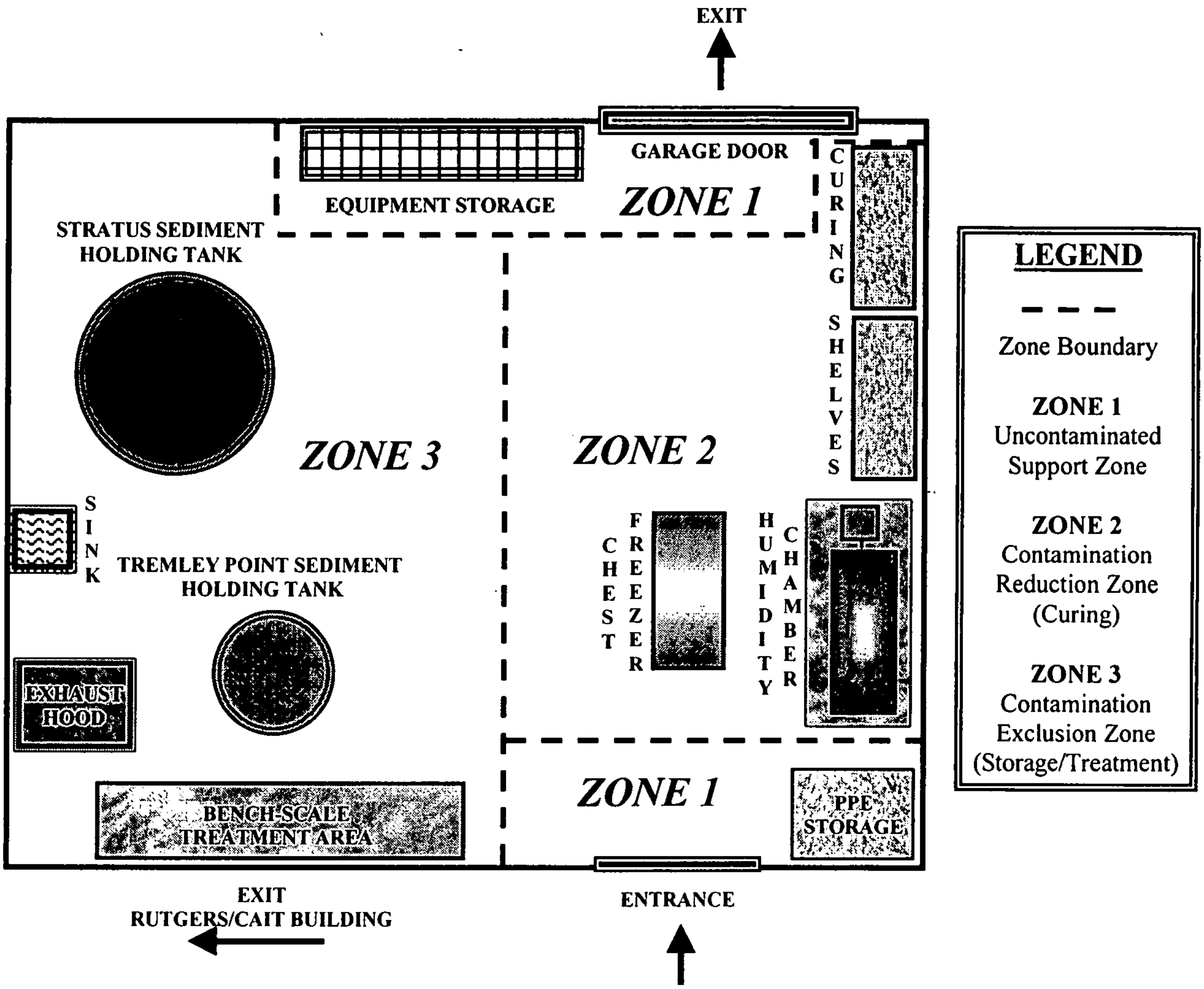
- Zone 1 is the uncontaminated support zone. Zone 1 is the area accessed upon entry into the laboratory, and where all equipment was stored after decontamination. All necessary personal protective equipment (PPE) was stored and used in this zone, prior to entry into other zones;

- Zone 2 is the contamination reduction zone of the laboratory where all treated dredged material is staged. Zone 2 includes shelves used to cure bench-scale treated and pilot stage treated material cured under room temperature conditions. In addition, Zone 2 includes set-up for materials cured under adverse weather conditions (e.g.. humidity chamber for material cured under > 95% humidity, and chest freezer for material cured at sub-zero temperature, etc.).

- Zone 3 is the contamination exclusion zone of the laboratory, where all untreated dredged material and Georemediation^{TM} reagents were stored. All bench-scale and pilot stage treatment and material transfer was also conducted inside the Zone 3;

All pilot operations were conducted in accordance with the procedures detailed in Quality Assurance Project Plan (QAPP) submitted to OMR in May 2001.

Figure 5-1: Rutgers/CAIT Laboratory Layout for BEM's Pilot Study of the Georemediation^{TM} Technology



The following reference photographs are included in Appendix A-1 for Section 5.1:

Photograph 5-1: BEM's Pilot Facility (Zones 1 & 3) – Rutgers/CAIT Laboratory

Photograph 5-2: BEM's Pilot Facility (Zone 3) – Rutgers/CAIT Laboratory

Photograph 5-3: BEM's Pilot Facility (Zones 2 & 3) – Rutgers/CAIT Laboratory

Photograph 5-4: BEM's Pilot Facility (Zone 2) – Rutgers/CAIT Laboratory

5.2 OMR Kick-Off Meeting/Source Material Site Visit

On 27 June 2000, prior to the contract execution, OMR scheduled a Sediment Pilot Project Kick-Off Meeting at the Stratus Petroleum Site in Newark, NJ. The following representatives from OMR and the regulatory agencies were among the attendees at the meeting:

- Scott Douglas (OMR);
- Lisa Baron (OMR);
- Henry Justus (OMR);
- Eric Stern (USEPA, Region 2);
- James Lodge (U.S. Army Corps of Engineers – NY District);
- Ajay Kathuria (BEM);

At the kick-off meeting, OMR informed the vendors that approximately 2,500 to 3,000 cubic yards of the source material was dredged from the Stratus Petroleum Site in November 1999 and stored in two open scows at Berth 22 in the Port Newark complex. A subsequent visit by OMR and the vendors to the storage location revealed that, during the seven months of storage in open scows, the material had naturally compacted and dried, with visible cracks on the surface. Vegetation had grown along the edges of the dried material inside both scows. The OMR intended to re-hydrate and re-homogenize the material prior to the distribution to various decontamination vendors.

The location of the Stratus Petroleum Site is shown in Figure 5-2. The material for the sediment decontamination projects was dredged from the navigable channels near the Stratus Petroleum Site.

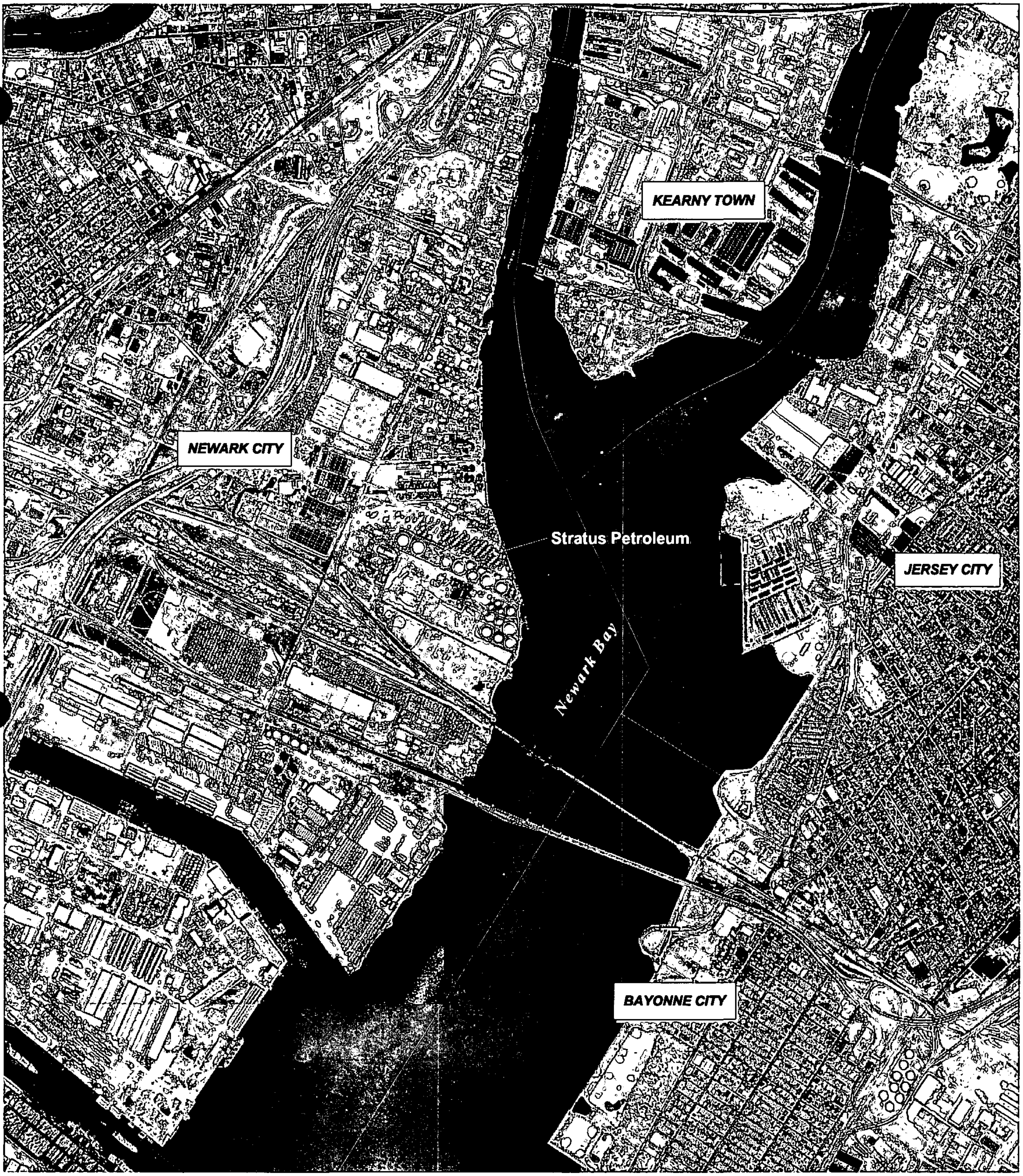
The following reference photographs are included in Appendix A-1 for Section 5.2:

Photograph 5-5:	Dredged Material from Stratus Petroleum Site Stored in Open Scows at Berth 22, Port Newark, NJ
Photograph 5-6:	Stratus Dredged Material – Visible Surface Cracks and the Vegetative Growth in Open Scows

5.3 Material Procurement – Stratus Petroleum Site

On 06 July 2000, OMR coordinated the re-hydration and re-homogenization of the Stratus material for the sample collection for BEM's pilot study. The OMR coordinated these activities with USACE, USEPA-Region 2, and JCI & Upcycle (decontamination vendor personnel) present. After the re-homogenization of the material, nineteen (19) 30-gallon drums were filled with the source material from the Stratus Petroleum Site for BEM's pilot study. The material was transported to a USACE Site at Chapel Avenue in Jersey City, NJ for subsequent pick-up by BEM.

On 12 July 2000, BEM, through its subcontractor EISCO-NJ, transferred the nineteen (19) 30-gallon drums containing the Stratus material to its Rutgers/CAIT facility. Prior to its use, the material was stored in the drums at room temperature in a staging area adjacent to the pilot facility.



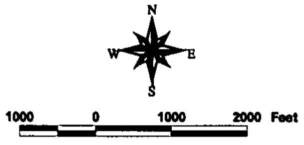


FIGURE 5-2
SEDIMENT DECONTAMINATION PILOT STUDY OF
THE GEOREMEDIATION TECHNOLOGY

Source Material (Stratus Petroleum)
Site Locations Map

November 21, 2001

BEM
SYSTEMS, INC.
100 Passaic Avenue
Chatham, NJ 07928
(908) 598-2600

Data Source:
Digital Orthophotography: NJDEP, 1995
Municipalities: ADCi, 1995

This map was produced using BEM's Geogrpahic Information System (GIS).

The following reference photographs are included in Appendix A-1 for Section 5.3:

Photograph 5-7: Use of Clamshell Bucket by OMR/USEPA to Re-Homogenize the Stratus Material

Photograph 5-8: Collection of Re-Homogenized Stratus Material in Nineteen (19) 30-Gallon Drums for BEM's Pilot Study

Photograph 5-9: Transfer of the Stratus Material by BEM, Through EISCO-NJ, to Rutgers/CAIT Facility

5.4 Additional Material Procurement – Tremley Point

On 27 June 2000, during the OMR Kick-Off Meeting, some of the decontamination vendors, including BEM, expressed concern that the source material was not representative of the in-situ conditions due to its storage in the open scows for more than seven months. The vendors were concerned that the direct exposure to sunlight and inclement weather conditions could have had a significant impact on the levels and types of volatile and certain semi-volatile organic contaminants that would be present in the sediments.

In response to these concerns, Mr. Scott Douglas (OMR) indicated that the use of the Stratus material was at the discretion of the decontamination vendor. However, freshly dredged contaminated sediments from another location may not be available until favorable dredging activities were scheduled. Therefore, BEM and other vendors agreed to use the Stratus material for the pilot study.

The results of BEM's characterization of the Stratus material in August 2000 indicated that no pollutants were present that exceeded the NJDEP's most stringent upland Residential Direct Contact Soil Clean-up Criteria (RDCSCC) for any of the following contaminant groups: Petroleum Hydrocarbons (TPHCs); Volatile Organic Compounds (VOCs); Semi-Volatile Organic Compounds (SVOCs); Pesticides/PCBs; and Metals. However, dioxins/furans were detected with an average total Toxicity Equivalent Quotient (TEQ) of 205 ppt, above the ATSDR guidance levels of 50 ppt for unrestricted upland use.

Due to significantly low levels of contaminants in Stratus material, BEM re-expressed its concern to OMR that the material being provided is not representative of the dredged material likely to be received during demonstration and full-scale treatment due to extended storage. In response, OMR allowed BEM to collect additional contaminated material within the pilot study budget, with the assistance from USEPA, Region 2 and USACE, NY District.

On 22 March, 2001, BEM collected approximately 200 gallons of additional contaminated dredged material from Tremley Point location, as shown in Figure 5-3. The Tremley Point location was selected after field screening of samples collected from several locations previously identified by Mr. Eric Stern (USEPA, Region 2) using immunoassay test kits for PAHs and PCBs. The immunoassay field screening locations are also shown on Figure 5-3. Further details on the collection of additional contaminated material, and procedures followed for the field screening using immunoassay test kits are included in Appendix A-2.

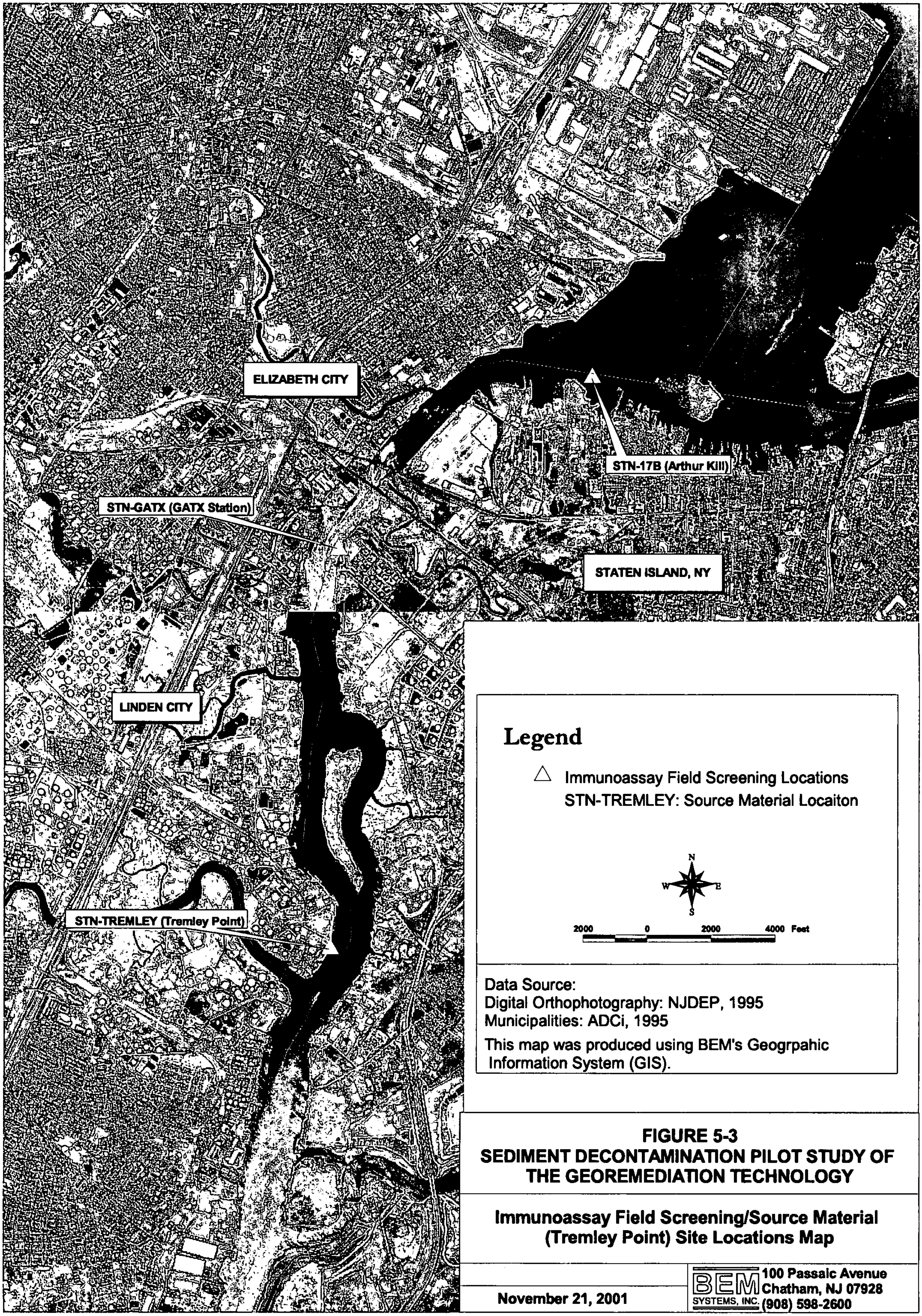
The following reference photographs are included in Appendix A-1 for Section 5.4

Photograph 5-10: Additional Contaminated Dredged Material Collection – USACE Boat (Gelberman) for the Operation

Photograph 5-11: Material Collected from Screening Locations for Immunoassay Testing

Photograph 5-12: Additional Contaminated Material Field Screening – Example of Immunoassy Field Screening Results (PAHs)

Photograph 5-13: Additional Contaminated Material Collection – Tremley Point



Legend

△ Immunoassay Field Screening Locations
STN-TREMLEY: Source Material Locaiton

Data Source:
Digital Orthophotography: NJDEP, 1995
Municipalities: ADCi, 1995

This map was produced using BEM's Geogrpahic Information System (GIS).

FIGURE 5-3
SEDIMENT DECONTAMINATION PILOT STUDY OF THE GEOREMEDIATION TECHNOLOGY

Immunoassay Field Screening/Source Material (Tremley Point) Site Locations Map

November 21, 2001

BEM SYSTEMS, INC.
100 Passaic Avenue
Chatham, NJ 07928
(908) 598-2600

5.5 Storage and Pretreatment

In July 2000, nineteen (19) 30-gallon drums containing the Stratus material were transported to BEM's Rutgers/CAIT pilot facility and stored at room temperature.

On 04 October 2000, BEM initiated the pre-treatment and preparation of the Stratus material as detailed below:

5.5.1 Screening/Transfer – Stratus Material

The Stratus material stored in nineteen (19) 30-gallon drums was transferred into a 675-gallon cylindrical polyethylene tank (6.5' diameter, 3.85' height) using a standard battery operated straddle-type Roto-Lift. Initially, the drummed material was poured over a stainless steel screen (Type 304, 1" opening) that had been placed on top of the holding tank. The purpose of the screen was to remove any large-debris that could interfere with proper homogenization and treatment of the material. During this debris filtering process, BEM experienced significant operational difficulties passing the material through the screens due to relatively higher percent solids than typically expected of the dredged material. In addition, the screening was likely made difficult due to the inconsistent re-hydration and re-homogenization efforts of the material prior to its distribution to various vendors by OMR.

Due to the operational difficulties and the minimal debris encountered, BEM discontinued the cumbersome screening process after only a few drums and transferred the remaining drummed material directly into the holding tank without screening. Any unusually large pieces of debris that appeared during the un-screened material transfer were manually removed during or after the transfer into the holding tank.

A total of 6,213 lbs, approximately 565 gallons, of Stratus material were recovered from the nineteen (19) 30-gallon drums, as detailed in Table 5-1. The individual 30-gallons drums were weighed before and after the material transfer in an effort to determine the total amount of material transferred from the drums. In addition, approximately 30 gallons (~250 lbs) of tap water was assumed to be added to the Stratus material with a pressured hose nozzle in order to facilitate transfer of the material from the drums into the holding tank. By the end of the material transfer, the holding tank consisted of approximately 6,463 lbs (595 gallons) of slightly diluted Stratus sediment material.

Table 5-1: Weight Measurements of Source Material from Stratus Petroleum Site

Drum #	Initial Weight (lbs)	Empty Weight (lbs)	Sediment Weight (lbs)	PID Reading[a] (ppm)
1	345	20	325	0.0
2	345	19	326	0.0
3	334	22	312	4.0[b]
4	360	19	341	0.0
5	345	21	324	0.0
6	354	17	337	0.0
7	337	16	321	0.0
8	341	17	324	0.0

Drum #	Initial Weight (lbs)	Empty Weight (lbs)	Sediment Weight (lbs)	PID Reading[a] (ppm)
9	343	19	324	0.0
10	350	20	330	0.0
11	347	21	326	0.0
12	352	20	332	0.0
13	361	21	340	0.0
14	352	21	331	0.0
15	350	19	331	0.0
16	347	19	328	0.0
17	343	17	326	0.0
18	336	19	317	0.0
19	339	21	318	0.0
Total (As Received) Sediment Weight			6,213	N/A
Tap Water Added			250	N/A
Total Sediment Weight			6,463	N/A

[a] PID readings for volatile emissions were taken immediately after the drum lids were removed
[b] The PID readings in drum #3 dropped to 0 ppm after approximately 30 seconds

As presented in Table 5-1, no volatile emissions were observed as indicated by the photo-ionization detector (PID) readings, with the exception of emissions monitored from drum #3. The volatile emission reading for drum #3 was initially found to be 4 ppm, however, within 30 seconds, the reading had dropped to non-detect. After all of the material had been transferred into the 675-gallon holding tank, no additional volatile emission readings were detected within the holding tank.

The PID readings for the volatile emissions recorded in Table 5-1 may not be representative of the typical material dredged from the navigable channels of the NY/NJ Harbor, due to significant storage (seven months) of the material in the scows open to the atmosphere at the Port Newark Complex. Therefore, the PID readings and the air emissions tests conducted further in this study may largely be considered incomplete.

not needed to be harped on

The following reference photographs are included in Appendix A-1 for Section 5.5.1:

Photograph 5-14: Stratus Material Transfer Operation Set-Up

Photograph 5-15: Stratus Material Screening Operational Difficulties

Photograph 5-16: Stratus Material Transfer Using Roto-Lift

5.5.2 Homogenization – Stratus Material

On 11 October 2000, BEM performed the initial homogenization of the Stratus material. To achieve homogenization, two (2) ½ hp gear-driven, dual propeller mixers were inserted vertically into the holding tank. The mixers were clamped onto two (2) 2"x4" wooden planks, which had been stacked and nailed together and placed across the diameter of the holding tank. The mixers were spaced approximately 3.5 feet from each other. The mixer shafts were 48" long and bottom of the mixer shafts were approximately 6" above the bottom of the holding tank. As per the manufacturer's recommendations, the two (2) 8"-diameter propellers were attached to each mixer shaft at a distance of at least 15" from each other. The four propellers, two on each shaft, were staggered at varying depths so that mixing would occur over the entire depth, approximately 3.5', of the Stratus material in the holding tank.

The consistency of the Stratus material stored in the holding tank appeared to have a higher percent solids composition than the 35-50% solids expected from dredged material. For material handling operations, it was desirable to work with the material with the consistency anticipated at the full-scale treatment level. In an attempt to correct for the unusually high percent solids composition, an additional 70 gallons of tap water was added to achieve the desired percent solids (typically 45-50%) that would facilitate the homogenization required for the pilot study.

possibility of salt/fresh issue here

The addition of tap water may likely change the partitioning of the contaminants within the sediment matrix, thereby jeopardizing the representativeness of the sediment samples for the pilot study. However, since the material was stored for long period of time in the open, prior to re-hydration and homogenization, OMR verbally approved the addition of tap water, provided an initial baseline characterization of the material was performed after homogenization and prior to further treatment and testing.

During 11-13 October 2000, BEM homogenized the material for approximately 12 hours using the two dual-propeller mixers. In order to achieve thorough homogenization, the dual-propeller mixers were rotated in a circular motion around the tank. After homogenization was completed on 13 October 2000, samples were withdrawn for a laboratory test to determine the solids content of the homogenized Stratus material. Table 5-2 presents the results of the duplicate moisture content test using standard ASTM Method D 2216. The average percent solids for the untreated homogenized Stratus material was estimated to be 51%.

Table 5-2: Percent (%) Solids Analysis Results for Stratus Material

Initial Sample Weight (g)	Final Sample Weight (g)	% Solids[a]
300	146	49%
300	156	52%
Average Solids Content (%)		**51%**

[a] % solids calculated as: (weight of dry solids/total weight of wet sediments)x100

The following reference photographs are included in Appendix A-1 for Section 5.5.2:

Photograph 5-17:	Stratus Material Transferred to the Holding Tank
Photograph 5-18:	Homogenization of the Stratus Material with Two (2) 0.5-HP Dual Propeller Blade Mixers
Photograph 5-19:	Manual Rotation of the Mixers around the Stratus Material Holding Tank for Proper Homogenization

5.5.3 Screening/Transfer – Tremley Point Material

On 23 March 2001, BEM's subcontractor, EISCO-NJ, transferred seven (7) 30-gallon drums containing additional sediment sample collected from the Tremley Point location. The material was transferred from the USACE site at Chapel Avenue, Jersey City to Rutgers/CAIT facility in Piscataway, NJ.

On 06 April 2001, BEM took simultaneous VOC and H_2S headspace readings with a calibrated PID as the storage drums containing the Tremley Point material were opened. Table 5-3 summarizes the PID and H_2S readings for the seven (7) 30-gallon drums.

Table 5-3: PID and H_2S Measurements for Source Material from Tremley Point

Drum #	PID Reading[a] Initial (ppm)	PID Reading[a] Agitated (ppm)	H_2S Reading Initial (ppm)	H_2S Reading Agitated (ppm)
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	23	17	0	0
5	0	1	0	6
6	0	0	0	0
7	0	1	0	3

[a] PID readings for any volatile emissions were taken immediately after the drum lids were removed

On 26 April 2001, BEM transferred the contents of the seven (7) 30-gallon drums containing the Tremley Point material into a cylindrical polyethylene 315-gallon tank (48" diameter, 42" height). Instead of straddle-type Roto Lift previously used for the Stratus material, the Tremley Point material was transferred into the holding tank with the aid of a gasoline powered 3-inch diaphragm mud pump. A 1"-screen basket at the suction head of the mud pump was used to screen unwanted debris during the material transfer. Approximately 200-gallons of Tremley Point material was transferred to the holding tank.

The following reference photographs are included in Appendix A-1 for Section 5.5.3:

Photograph 5-20: Tremley Point Material Transfer with Mud Pump

Photograph 5-21: Homogenization of the Tremley Point Material with Two (2) 0.5-HP Dual Propeller Blade Mixers

5.5.4 Homogenization – Tremley Point Material

After the transfer of the material into the holding tank, the Tremley Point material was homogenized with the same methods and equipment used for the homogenization of the Stratus material, as described in Section 5.5.2.

The following reference photographs are included in Appendix A-1 for Section 5.5.4:

Photograph 5-21: Homogenization of the Tremley Point Material with Two (2) 0.5-HP Dual Propeller Blade Mixers

5.6 Characterization of the Source Materials

Prior to further handling and treatment, the Stratus and the Tremley Point materials were sampled and analyzed in order to obtain complete chemical characterizations of both materials as per the requirements of the October 1997 NJDEP Technical Document. The sampling procedures for the characterization of the source materials are presented in the sections below.

5.6.1 Stratus Material Characterization

5.6.1.1 Initial Characterization Sampling

Sampling for the initial characterization of the Stratus material was conducted on 13 October 2000, immediately following the Stratus material homogenization. In an effort to obtain samples that best represented the chemical composition of the Stratus material in the holding tank, triplicate samples (SEU1, SEU2, and SEU3) were submitted for chemical analysis. Each of the triplicate samples was a composite of five (5) samples taken from different locations and varying depths in the holding tank. The 5-part triplicate samples were composited in the laboratory on an equal weight basis, prior to the chemical analysis.

For sampling, the material in the holding tank was divided into four compartments as shown in Figure 5-2: Zone 1, Zone 2, Zone 3, Zone 4, with additional sampling locations at the center of the tank. The four (4) compartments and the center of the tank were further divided into three depths (A [top]: 0-13"; B [middle]: 13-26"; C [bottom]: 26-39"). A total of fifteen (15) parts were used to produce the three (3) composite samples and each part was collected in separate jars from each of the five sampling areas and the three varying depths. Table 5-4 summarizes which of the 15 parts collected were used in preparing each of the three composite samples that were analyzed for the Stratus material's initial characterization.

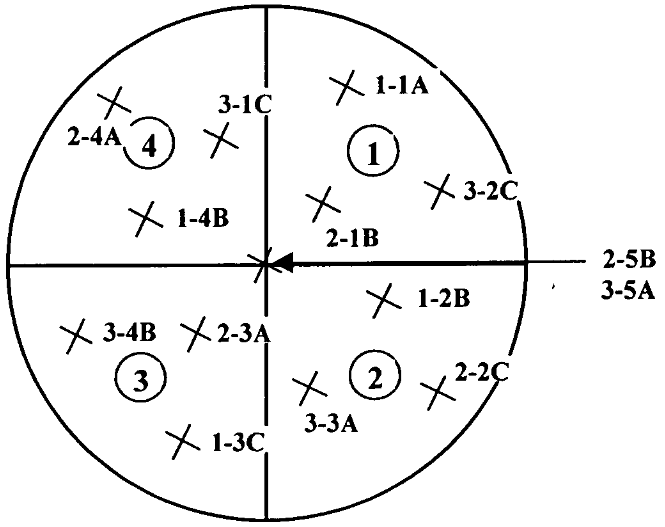
It should be noted that due to the "zero" headspace requirement for samples being analyzed for VOCs, the laboratory could not composite the parts for the samples and therefore, parts for the samples were obtained from the Stratus material and composited by BEM. For the VOC analysis in triplicate (SEU Comp-1V, SEU Comp-2V, and SEU Comp-3V), BEM collected nine parts at various locations in holding tank and composited three parts into each of the triplicate samples.

Table 5-4: Initial Stratus Material Characterization Sample Identifications

Composite Sample Identification	Composite Parts Identification[a]
SEU1	SEU1-1A
	SEU1-2B
	SEU1-3C
	SEU1-4B
	SEU1-5C
SEU2	SEU2-1B
	SEU2-2C
	SEU2-3A
	SEU2-4A
	SEU2-5B
SEU3	SEU3-1C
	SEU3-2C
	SEU3-3A
	SEU3-4B
	SEU3-5A

[a] Locations of the 5-part sample identifications are presented in Figure 5-4 without the prefix "SEU" (e.g. "SEU1-1A" is presented as "1-1A")

Figure 5-4: Initial Stratus Material Characterization Sampling Plan from the Holding Tank



The parts collected from the various compartments and depths of the holding tank were collected using a 6' long hand-auger. All screening, instrument calibration, sampling, equipment decontamination, and record keeping was conducted in accordance with the procedures outlined in BEM's Quality Assurance Project Plan (QAPP) dated 31 May 2001 and submitted to NJMR.

The samples collected for the initial characterization of the Stratus material were analyzed by a NJDEP certified analytical laboratory for the parameters listed in Table 5-5.

Table 5-5: Initial Stratus Material Characterization Sample Identifications and Analytical Parameters

Sample Identification	Parameter(s)
SEU1 SEU2 SEU3	pH Chloride, Resistivity, Sulfate, Sulfide TAL-Metals TCL-BNA+20 TCL-PCB TCL-Pesticides TOC TPHC Dioxin/Furans
SEU Comp-1V SEU Comp-2V SEU Comp-3V	TCL-VOC+10

The results from the initial characterization of the Stratus material were used to establish the project's health and safety procedures, as well as the QA/QC procedures that were to be used during the pilot study. These results were also used as a baseline against which the results from the bench-scale treatments would be compared. This comparison would allow BEM to select which the Georemediation™ reagent and reagent loading rate should be used for the pilot-scale treatment.

5.6.1.2 Re-Characterization Sampling

The Stratus material used for the pilot-scale treatment was re-characterized in order to ensure the accuracy and representativeness of the contamination levels in the material. On 17 August 2001, approximately ten (10) months after initial characterization, BEM collected duplicate composite samples for the re-characterization of the Stratus material.

Prior to re-characterization sampling, the Stratus material was thoroughly homogenized using the same procedures used during the initial characterization. Each sample consisted of 5-parts collected from staggered locations and depths from within each half of the holding tank and composited by BEM on equal weight basis at the pilot facility prior to submission to the analytical laboratory for analysis. The composite samples collected were designated as SEU41 and SEU42. Table 5-6 presents the Sample Identifications and analytical parameters for the re-characterization of the Stratus material.

Table 5-6: Subsequent Stratus Material Characterization Sample Identifications and Analytical Parameters

Sample Identification	Parameter(s)[a]
SEU41 SEU42	pH Chloride, Resistivity, Sulfate, Sulfide TAL-Metals TCL-BNA+20 TCL-PCB TCL-Pest TOC TPHC Dioxin/Furans

[a] No TCL-VOC+10 analysis was performed on the re-characterization samples due to low to non-detect levels observed during the initial characterization sampling

The following reference photographs are included in Appendix A-1 for Section 5.6.1:

Photograph 5-22: Stratus Material Initial Characterization Sampling

5.6.2 Tremley Point Material Characterization

On 26 April 2001, BEM collected duplicate composite samples from the Tremley Point material holding tank. The samples were collected as 5-part field composites using the sampling procedures employed for the Stratus material re-characterization sampling. The raw material composite samples were designated as TPU-1 and TPU-2. Table 5-7 presents the sample identifications and analytical parameters for the characterization of the Tremley Point material.

Table 5-7: Temley Point Material Characterization Sample Identifications and Analytical Parameters

Sample Identification	Parameter(s)
TPU-1 TPU-2	pH Chloride, Resistivity, Sulfate, Sulfide TCL-VOC+10 TAL-Metals TCL-BNA+20 TCL-PCB TCL-Pest TOC TPHC Dioxin/Furans

5.7 Bench-Scale Testing

BEM conducted bench-scale testing on both the Stratus and the Tremley Point materials, in order to determine the Georemediation^{TM} mix type and loading rate (% loading by weight) estimated to achieve maximum decontamination effectiveness, as established in the success criteria.

A total of five (5) Georemediation^{TM} mix types (Mix 1 through Mix 5) were tested at various percent loadings (generally 10% and/or 20%) at the bench-scale level during this pilot study. Table 5-8 provides the general compositions of the five (5) Georemediation^{TM} mix types used, along with their approximate density (lb/ft^3), as measured in the laboratory.

Table 5-8: General Composition and Density of Georemediation^{TM} Mixes

Georemediation^{TM} Mix Type / Composition	Compositional Distribution (%)	Density (lb/ft^3)
Mix 1		80.7
Portland Cement	50%	
Steel Blast Furnace Slag	42%	
Transition Metal Catalyst #1[b]	8%	
Mix 2		65.1
Portland Cement	50%	
Fly Ash	42%	
Transition Metal Catalyst #1[b]	8%	
Mix 3		57.5
Portland Cement	50%	
Fly Ash	40%	
Transition Metal Catalyst #1[b]	10%	
Phosphoric Acid (H_3PO_4) Solution (0.6%)	Used instead of tap water for reagent slurry	
Mix 4		88.7
Portland Cement	50%	
Nucem[a]	42%	
Transition Metal Catalyst #2[b]	8%	
Mix 5		88.7
Portland Cement	50%	
Nucem[a]	42%	
Transition Metal Catalyst #1[b]	8%	

[a] "Nucem" is a commercial name for a material, which is a source of high silicate materials and transition metal oxides

[b] Due to proprietary nature of the materials used, the actual chemical names for the "Transition Metal Oxides" are not provided

Prior to each bench-scale treatment, the source materials (Stratus or Tremley Point) in the holding tanks were thoroughly homogenized as documented in the procedures detailed in Sections 4.5.2 and 4.5.4. The following procedures describe the general steps of the bench-scale operations:

- Approximately 2,500 grams (g) of homogenized raw material was weighed, using a laboratory balance (accuracy 0.1 g), and then transferred into a bench-top blender with a 1-gallon capacity;
- Approximately 250 g (for 10% loading), or 500 g (for 20% loading), of the Georemediation^{TM} mix was weighed in a 1000 ml glass beaker;
- An equal weight of water (250 g for 10% loading or 500 g for 20% loading) was added to the Georemediation^{TM} mix and manually blended with a plastic spatula for approximately 1 minute (or as appropriate) to form the reagent slurry;
- The reagent slurry was then transferred into the bench-top blender bowl which contained the untreated sediment material;
- The variable speed laboratory blender was operated at the maximum allowable speed (which resulted in minimal splashing) for approximately 5 minutes to allow for thorough exposure of the raw material to the Georemediation^{TM} reagent slurry;
- The newly treated material was transferred into open plastic curing pans (approximately 18" x 10" x 4") and allowed to cure at room temperature in the laboratory;
- After a 14-day curing period, the cured samples were manually homogenized with spatulas;
- Duplicate samples of the treated and homogenized material were collected from the curing pans and sent to the analytical laboratory for chemical analysis.

The initial Georemediation^{TM} mixes (Mix 1 and Mix 2) were designed by the technology developer Mr. Jeff Newton of Aleph Group, and bench-scale tested by BEM on both Stratus and Tremley Point material based on the characterization results of the untreated materials. As later presented in Section 6.0, these bench-scale results were used to select the most chemically effective Georemediation^{TM} reagent mix type (Mix 2) and loading rate (10%) for further testing at the pilot scale using Stratus material. However, due to deficiencies observed in the pilot test results, additional rounds of bench-scale tests were conducted on both Stratus and Tremley Point material to further improve upon the chemical effectiveness of the Georemediation^{TM} reagents, in order to achieve chemical efficacy success criteria. Additional bench-scale tests were conducted using Mix3, Mix 4, and Mix 5 on Stratus material.

A detailed description of the methods and procedures followed during various bench-scale tests is provided in the subsections that follow. All methods and procedures used for the pilot-scale tests are provided in Section 5.8.

Following the presentation of complete bench-scale and pilot-scale results in Section 6.1, a detailed discussion and a graphical flow-chart (Figure 6-20) on the sequence and decision making process for various bench-scale tests, pilot-scale test, and the selection of Georemediation^{TM} reagent mixes and loading rates is presented in Section 6.2.

5.7.1 Stratus Material Bench-Scale Testing –Round 1

On 20 December 2000, BEM conducted the first round of bench-scale tests on the Stratus material. As a result of the initial estimate of approximately 51% solids, BEM further diluted the Stratus bench-scale test samples to achieve approximately 45% solids, as previously assumed and presented in the final pilot study workplan.

Table 5-9 presents a summary of the Georemediation™ mix types, loading rates, curing period, number of treated samples, sample identifications, and analytical parameters for the first round of bench-scale tests completed using the Stratus material.

Table 5-9: Stratus Material Bench-Scale Testing Program – Round 1

Test Parameter	**Mix 1**		**Mix 2**	
	10%	**20%**	**10%**	**20%**
Samples Analyzed After 14-Day Curing Period				
# of Samples Collected	2	2	2	2
Sample Identification(s)	SETM11014-1 SETM11014-2	SETM12014-1 SETM12014-2	SETM21014-1 SETM21014-2	SETM22014-1 SETM22014-2
Analytical Parameter(s)[a]	Dioxins/Furans	Dioxins/Furans	Dioxins/Furans	Dioxins/Furans

[a] The samples were analyzed only for dioxins/furans since no other contaminants were either detected or were above the decontamination efficacy success criteria (NJDEP RDCSCC) during initial Stratus characterization

The following reference photographs are included in Appendix A-1 for Section 5.7.1:

Photograph 5-23:	Stratus Material Bench-Scale Treatment
Photograph 5-24:	Curing Pans for the Bench-Scale Treated Stratus Material
Photograph 5-25:	Bench-Scale Treated and Homogenized Stratus Material after 14-Day Curing Period – Mix 1 Treatment (Top) and Mix 2 Treatment (Bottom)
Photograph 5-26:	Sampling of the Bench-Scale Treated Stratus Material

5.7.2 Tremley Point Material Bench-Scale Testing –Round 1

On 03 May 2001, BEM conducted first round of bench-scale treatment on the Tremley Point material, using the same Georemediation™ mix types and loading rates used for the Stratus bench-scale tests. The first round of Stratus material bench-scale chemical analysis focused on the dioxins/furans concentrations, however, the Tremley Point bench-scale analysis were used to determine the effectiveness of the Georemediation™ treatment on other target organic and metals contaminants. More organic contaminants (pesticides, PCBs, etc.) were detected at low levels in Tremley Point material as compared to the Stratus material. The characterization results for Tremley Point material indicated that only arsenic (As) [27.6 mg/kg] and dioxins/furans (total TEQ of 140 ppt) exceeded the RDCSCC or TEQs criteria for unrestricted re-use.

Table 5-10 summarizes the Georemediation^{TM} mix types, loading rates, curing period, number of treated samples, sample identifications, and analytical parameters for the first round of bench-scale tests completed using the Tremley Point material.

Table 5-10: Tremley Point Material Bench-Scale Testing Program – Round 1

Test Parameter	Mix 1		Mix 2	
	10%	20%	10%	20%
Samples Analyzed After 14-Day Curing Period				
No. Of Replicates	2	2	2	2
Sample Identification(s)	TPOM110 TPOM110Dup	TPOM120 TPOM120Dup	TPOM210 TPOM210Dup	TPOM220 TPOM220Dup
Analytical Parameter(s)	pH Chloride, Resistivity, Sulfate, Sulfide TAL-Metals TCL-BNA+20 TCL-PCB TCL-Pest TOC TPHC	pH Chloride, Resistivity, Sulfate, Sulfide TAL-Metals TCL-BNA+20 TCL-PCB TCL-Pest TOC TPHC	pH Chloride, Resistivity, Sulfate, Sulfide TAL-Metals TCL-BNA+20 TCL-PCB TCL-Pest TOC TPHC	pH Chloride, Resistivity, Sulfate, Sulfide TAL-Metals TCL-BNA+20 TCL-PCB TCL-Pest TOC TPHC
Samples Analyzed After 52-Day Curing Period				
No. Of Replicates	2		2	
Sample Identification(s)	TPOM11052 TPOM11052-Dup	N/A	TPOM21052 TPOM21052-Dup	N/A
Analytical Parameter(s)[a]	TAL-Metals TCL-BNA+20 TPHC	N/A	TAL-Metals TCL-BNA+20 TPHC	N/A

[a] The samples after 52-day curing period were analyzed for selected percent loading (10%) and parameters to evaluate further improvement in decontamination and also address poor replication (RPD) in PAHs data for one of the treatments after 14-day curing (Mix 2, 10% loading) as detailed in Section 6.0 Results.

N/A – Not Analyzed

5.7.3 Tremley Point Material Bench-Scale Testing –Round 2

On 06 September 2001, BEM conducted a second round of bench-scale tests on the Tremley Point material. Although, the first round of bench-scale tests on Stratus and Tremley Point material provided a Georemediation^{TM} mix and loading rate that appeared to be most effective in reducing low levels of organic contaminants, the results were largely ineffective on metals, specifically arsenic (As).

The second round of bench-scale tests on Tremley Point material was conducted to further improve the Georemediation^{TM} decontamination effectiveness for metals, specifically arsenic, while achieving equal or better decontamination effectiveness for the organic contaminants. For this purpose, Georemediaton^{TM} Mix 3 was developed by Mr. Newton and bench-tested on Tremley Point material. Mix 3 was added to the untreated sediments as a slurry with 1:1 ratio of reagent to a 0.6% phosphoric acid (H_3PO_4) solution, instead of tap water. Phosphoric acid was added to aid in the precipitation and immobilization of arsenic in the treated material. The treated Tremley Point material was sampled in duplicate after a 28-day curing period, instead of typical 14-day curing period, due to unavoidable schedule conflicts.

Table 5-11 summarizes the Georemediation^{TM} mix type, loading rates, curing period, number of treated samples, sample identifications, and analytical parameters for the second round of bench-scale tests completed using the Tremley Point material.

Table 5-11: Tremley Point Material Bench-Scale Testing Program – Round 2

Test Parameter	**Mix 3**	
	10%	**20%**
Samples Analyzed After 28-Day Curing Period		
No. Of Replicates	2	2
Sample Identification(s)	TPOM31028-1 TPOM31028-2	TPOM32028-1 TPOM32028-2
Analytical Parameter(s)	pH Chloride, Resistivity, Sulfate, Sulfide TAL-Metals TCL-BNA+20 TCL-PCB TCL-Pest TOC TPHC	pH Chloride, Resistivity, Sulfate, Sulfide TAL-Metals TCL-BNA+20 TCL-PCB TCL-Pest TOC TPHC

5.7.4 Stratus Material Bench-Scale Testing –Round 2

On 30 October 2001, BEM conducted a second round of bench-scale tests on the Stratus material using two additional Georemediation^{TM} mix types (Mix 4 and Mix 5). This second round of testing was deemed necessary for the following reasons:

- Mix 1, Mix 2, and Mix 3 were unsuccessful in significantly reducing specific metals concentrations in both the Stratus and the Tremley Point material, as later presented in Section 6.0.
- The results of the MEP leaching test, conducted on the Stratus material during the pilot stage, indicated that the treatment was not successful in preventing the leaching of certain metals contaminants below the NDJEP groundwater quality standards (GWQS) for all of the seven (7) MEP leaching steps. This could restrict the beneficial use of the treated material in certain upland situations, thereby affecting its market potential;
- The high percent reductions (> 90%) for dioxins/furans seen during the Stratus material bench-scale testing (Round 1) were not repeated during pilot stage using similar treatment conditions, with significantly lower and inconsistent reductions observed for dioxins/furans. As later determined, the high percent reductions (>90%) observed at the bench-scale level were a result of inaccurate data provided by the analytical laboratory without BEM's knowledge. This problem was discovered only after BEM selected the Georemediaton^{TM} mix (Mix 2) and loading rate (10%) for the pilot treatment stage. The analytical issues related to the dioxins/furans analysis are further discussed in Section 6.3.

what was the problem?

Based on the results of the previous bench-scale and pilot tests, and the laboratory analytical issues described above, BEM deemed it necessary to conduct additional bench-scale tests on the Stratus material.

Table 5-12 summarizes the Georemediation™ mix types, loading rates, curing period, number of treated samples, sample identifications, and analytical parameters for the second round of bench-scale testing on Stratus material.

Table 5-12: Stratus Material Bench-Scale Testing Program – Round 2

Test Parameter	**Mix 4**	**Mix 5**
	10%	**10%**
Samples Analyzed After 14-Day Curing Period		
No. Of Replicates	2	2
Sample Identification(s)	SETM41014-1 SETM41014-2	SETM51014-1 SETM51014-2
Analytical Parameter(s)	TAL-Metals Dioxins/Furans MEP Leaching Test[a]	TAL-Metals Dioxins/Furans MEP Leaching Test[a]

[a] The MEP leachate from all seven (7) extraction steps was analyzed for arsenic (As) and lead (Pb) only

5.8 Pilot Treatment

The main objective of the pilot treatment stage of this study was to simulate anticipated operational, treatment, and curing conditions that may impact the effectiveness, and consequently, the economics of the Georemediation^{TM} treatment at the demonstration and full-scale level. Since the pilot study was conducted in a closed Rutgers laboratory with physical constraints on a relatively small amount of material (approximately 600 gallons of total Stratus material), large-scale simulations of the treatment and curing processes were not feasible.

Pilot treatment was conducted on the Stratus material following the results of the first round of bench-scale treatments. The most chemically effective Georemediation^{TM} mix type (Mix 2) and loading rate (10%) determined at the bench-scale level based primarily on the dioxins/furans results was used to study the operational parameters at the pilot treatment stage.

On 17 August 2001, prior to the pilot treatment, the untreated Stratus material was re-homogenized and re-characterized due to extended (approximately 10 months) since the initial characterization. The re-characterization data for the Stratus material was strictly used for comparison with the treated data obtained during the pilot treatment stage. In addition to re-homogenization, BEM conducted laboratory moisture content (solids content) tests using standard ASTM Method D 2216. Table 5-13 presents the results of the duplicate moisture content (percent solids) test, with average percent solids of 42% determined for the Stratus material.

Table 5-13: Percent (%) Solids Analysis Results for Stratus Material

Initial Sample Weight (g)	Final Sample Weight (g)	% Solids
256	106	41%
160	68	43%
Average Solids Content (%)		**42%**

5.8.1 Pilot Treatment and Curing Conditions

In order to achieve the pilot objectives detailed in Section 4.1, the following five (5) treatment and curing conditions were employed using selected Georemediaton^{TM} Mix 2 at 10% loading by weight of wet sediments, during the pilot treatment stage:

6. Slurried reagent addition (1:1 reagent to tap water ratio by weight), followed by curing at room temperature **(RT)**;
7. Slurried reagent addition (1:1 reagent to tap water ratio by weight), followed by curing at high relative humidity **(RH > 95%)**;
8. Slurried reagent addition (1:1 reagent to tap water ratio by weight), followed by curing at freezing temperatures (approximately 15° F) **[FR]**;
9. Slurried reagent addition (1:1 reagent to tap water ratio by weight), followed by curing in deeper curing pile (3 times deeper than the other piles, with relatively same surface area) **[DP]**;
10. Dry powder reagent addition (without tap water), followed by curing at room temperature **(DRY)**.

5.8.2 Pilot Mixing Procedures

In general, same operational procedures were used for mixing the Georemediation™ reagent with the untreated Stratus material for all the five (5) treatment and curing conditions, except that in the 5th condition (DRY), Georemediation™ mix was added in dry powder form instead of a wet slurry. The following summarizes the general mixing procedures used during the pilot treatment stage:

- Approximately 15-20 gallon of untreated homogenized Stratus material was used for each batch of mixing with the Georemediation™ Mix 2;
- All treatment trains included mixing of one (1) sediments batch, except for the DP (deeper curing pile) condition, where three (3) sediment batches were mixed;
- A cement mixer (3-cu ft or 23-gallon capacity) was used for the mixing of the Stratus material with the Georemediation™ Mix 2;
- Untreated Stratus material was manually transferred from the holding tank into the cement mixer using 5-gallon plastic buckets. Prior to and after each transfer, the bucket was weighed to determine the total weight (in lbs) of the sediments transferred into the cement mixer;
- Approximately 10% Georemediation™ Mix 2, by weight of the total wet sediments in the cement mixer, was weighed into a 5-gallon plastic bucket;
- An equal weight of water (as the reagent weight) was added to the bucket with the Georemediation™ Mix 2, and thoroughly blended using a variable speed, hand held drill with an attached blender. The reagent slurry was generally blended for approximately 1-2 minutes or less, based on visual observation to achieve homogeneous mixing;
- The reagent slurry was immediately poured into the in-operation cement mixer and thoroughly rinsed with a minimal additional water (if required);
- The cement mixer was generally operated for approximately 10 minutes;
- For the treatment condition using dry reagent addition (DRY), the reagent was added as a dry powder into the in-operation cement mixer using a hand held plastic scoop. The reagent addition for one (1) sediments batch took approximately 5 minutes. The cement mixer was operated for additional 10 minutes after the addition of the dry reagent;
- The ambient room temperature, Stratus material core temperature, maximum reagent slurry temperature, and maximum temperature during the mixing of the reagent and Stratus material in the cement mixer were measured and recorded;
- After thorough blending, the material was transferred into appropriate plastic curing pans.

Table 5-14 provides a summary of the total amount of Stratus material and Georemediation™ reagent used for various treatment conditions.

Table 5-14: Material Weight Measurements for Various Pilot Treatment Conditions

Treatment Condition[a]	Stratus Material Weight (lbs)	Georemediation™ Mix 2 Weight (lbs)	Water Weight (lbs)	Total Treated Material Weight (lbs)
RT	162	16	16	194
RH > 95%	157	16	16	189
FR	160	16	16	192
DP[b]	224 170 263	22.5 17 26	22.5 17 26	269 204 315
DRY	158	16	0	174

[a] Treatment conditions have been previously explained in Section 5.8.1

[b] Weight measurements for three (3) separate batches are provided

The following reference photographs are included in Appendix A-1 for Section 5.8.2:

Photograph 5-27:	Manual Transfer of the Re-Homogenized Stratus Material for Pilot-Scale Treatment
Photograph 5-28:	Weight Measurements of Stratus Material Prior to the Transfer to the Cement Mixer for Pilot-Scale Treatment
Photograph 5-29:	Manual Transfer of the Stratus Material to the Cement Mixer
Photograph 5-30:	Georemediation™ Reagent Slurry Preparation
Photograph 5-31:	Addition of Water to the Georemediation™ Reagent for Slurry Preparation
Photograph 5-32:	Blending of the Water and Georemediation™ Reagent for Slurry Preparation
Photograph 5-33:	Direct Addition of the Dry Georemediation™ Reagent Powder for Pilot Treatment
Photograph 5-34:	Mixing of the Goremediation™ Reagent Slurry with the Stratus Material for Pilot Treatment
Photograph 5-35:	Temperature Measurements during Pilot Treatment using the Cement Mixer
Photograph 5-36:	Transfer of the Treated Stratus Material from the Cement Mixer into the Curing Pan

5.8.3 Pilot Curing Procedures

The Stratus material treated at the pilot stage was cured under the following conditions to study the impact on adverse weather conditions, and space constraints on the chemical decontamination efficacy during the demonstration or full-scale operations:

- Room temperature curing **(RT and DRY)**;
- Room temperature curing (deeper curing pile) **[DP]**;

- High relative humidity Curing **(RH > 95%)**;
- Freezing temperature Curing **(FR)**.

The following sections present general set-up and procedures followed for each type of curing conditions.

5.8.3.1 Room Temperature Curing (RT)

The Stratus material treated under the "RT" and "DRY" conditions was transferred into 36"x24"x6" polyethylene curing pans, and cured at room temperature inside the Rutgers CAIT laboratory. The curing pans were not exposed to any direct sunlight. The curing pans were uncovered at the top, and a bimetal dial thermometer (5"-stem) was inserted in the center of the pan to monitor any temperature changes.

The following reference photographs are included in Appendix A-1 for Section 5.8.3.1:

Photograph 5-37:	Room Temperature Curing of the Stratus Material Treated using Slurried Reagent (RT) at the Pilot-Scale
Photograph 5-38:	Room Temperature Curing of the Stratus Material Treated using Dry Reagent (DRY) at the Pilot-Scale

5.8.3.2 Room Temperature Curing – Deeper Curing Pile (DP)

The Stratus material treated under the "DP" condition was transferred into a 36"x24"x18" polyethylene curing pan, and cured at room temperature inside the Rutgers CAIT laboratory. The curing pan used under this condition was approximately three (3) times deeper than the regular pans used, and accommodated three (3) separate batches of treated Stratus material.

Prior to the material transfer, the deeper curing pan was perforated at the bottom along the length of the pan on both ends. The bottom of the pan was then filled with approximately 0.5" layer of gravel, and covered with a double-layered Geotextile. The purpose of the Geotextile and the gravel was to determine the potential for water run-off from the curing pan. The curing pan was placed on top of a plastic cover to collect any potential leachate from the cured material.

In addition to the placement of gravel and Geotextile, six (6) bi-metal dial thermometers were used to monitor the temperature variations among three different depths of the curing pan. For this purpose, the curing pan was vertically divided in three zones and three (3) bimetal dial thermometers (36"-stem) were inserted at the center of each zone along the length of the pan, and three (3) bimetal thermometers (24"-stem) were inserted at the center of each zone along the width of the curing pan.

The following reference photographs are included in Appendix A-1 for Section 5.8.3.2:

Photograph 5-39:	Deeper Curing Pan Set-Up – Bottom Perforation Covered with 0.5" of Gravel and Double Layer Geotextile
Photograph 5-40:	Deeper Curing Pan Set-Up – Placement of Temperature Thermometers along Three (3) Depth Zones
Photograph 5-41:	Room Temperature Curing of the Stratus Material in Deeper Curing Pan

5.8.3.3 High Relative Humidity Curing (RH > 95%)

BEM conducted curing under high relative humidity to study the effect of adverse weather conditions expected along NY/NJ Harbor, on the chemical effectiveness of the Georemediation^{TM} treatment. For this purpose, the curing pan with treated material was placed inside a specially constructed humidity chamber, capable of maintaining a constant relative humidity (RH > 95%).

The humidity chamber consisted of a clear plastic rectangular enclosure on a steel pipe frame with approximate dimensions of 60"x36"x24". The chamber was equipped with a zipper opening to allow the placement of the curing pan and subsequent sample collection from the material. The backside of the humidity chamber was covered with a plastic cardboard. A centrifugal atomizing "Through-the-Wall" humidifier, with 8000-cu ft effective area, was installed through the backside of the humidity chamber. The centrifugal humidifier was connected to a constant tap water supply through a ¾" plastic pipe. The humidity of the chamber was constantly monitored with a humidity reader and a humidifier control. In addition, a bimetal dial thermometer (5"-stem) was inserted at the center of the curing pan to record the temperature variations in the material during curing process.

The following reference photograph is included in Appendix A-1 for Section 5.8.3.3:

Photograph 5-42:	High Relative Humidity (RH > 95%) Curing of the Stratus Material in a Controlled Humidity Chamber

5.8.3.4 Freezing Temperature Curing (FR)

BEM conducted curing under freezing conditions to study the effect of adverse weather conditions (winter, snow, etc.) on the chemical effectiveness of the Georemediation^{TM} treatment. For this purpose, BEM placed the 36"x24"x6" curing pan with the material treated under the "FR" condition inside a chest freezer maintained at sub-zero temperature (approximately 15° F). A bimetal dial thermometer (5"-stem) was placed in the center of the curing pan to record temperature variations of the material during the curing process.

The following reference photographs are included in Appendix A-1 for Section 5.8.3.4:

Photograph 5-43:	Freezing Temperature (FR) Curing of the Stratus Material in a Controlled Chest Freezer
Photograph 5-44:	General Laboratory Set-Up for Curing under Adverse Weather Conditions

5.8.4 Pilot Sampling Procedures

The treated Stratus material under all five (5) conditions was cured for a period of 62 days and characterized through duplicate sample collection after 14-day, 28-day and 62-day curing period. At the end of each curing period, each of the duplicate samples was collected as a 10-part composite from sample cores collected at various locations inside the curing pan. The 10-parts were selected to allow the collection total sample volume required for the proposed analyses using the sampling tool selected.

For the material cured at room temperature (RT and DRY) and high humidity (RH > 95%) in 36"x24"x6" pans, samples were collected using a 22"-long stainless steel soil auger with a 1"-internal diameter. The auger also contained a perforated slit along its length (1/4" wide) for easy sample recovery. For each sample, auger was pushed into the material and cores were collected from 10 different locations spread out evenly through the curing pan. The samples recovered from each of the 10 augers were transferred into the bench-scale blender and thoroughly homogenized. The homogenized sample was transferred into sample bottles and appropriately labeled prior to submission to the analytical laboratory.

For material cured in deeper curing pile (DP), duplicate samples were collected after each curing-period from three separate depths. These depths, measured from the surface, were designated as Depth A (0-6"), Depth B (6"-12"), and Depth C (12-18"). Each of the samples was collected as a 10-part composite with sample augers advanced in the material at 10 different locations spread evenly through the curing pan. For each sampling event, an 18" long sample auger was inserted to the bottom of the curing pan, and sample collected was divided into three (3) parts, representing three (3) sampling depths. Individual parts from 10 different augers were thoroughly blended in a bench-scale mixer and transferred to sample bottles. The augers for the duplicate sample were generally advanced in the general vicinity of the 10 locations previously used for the composite sample collection. The sample bottles were appropriately labeled and submitted for laboratory analysis.

Table 5-15 provides a summary of sample identifications for all five (5) treatment conditions, after various curing periods. Duplicate samples were collected for all sampling events.

Table 5-15: Sample Identification for Pilot Treatment and Curing

Treatment and Curing Condition	Number of Replicates/ Curing Period	Sample Identification @ Curing Period		
		14-days	28-days	62-days
RT	2	SEM21014RT1 SEM21014RT2	SEM21028RT1 SEM21028RT2	SEM21062RT1 SEM21062RT2
DRY	2	SEM21014DRY1 SEM21014DRY2	SEM21028DRY1 SEM21028DRY2	SEM21062DRY1 SEM21062DRY2
RH > 95%	2	SEM21014RH1 SEM21014RH2	SEM21028RH1 SEM21028RH2	SEM21062RH1 SEM21062RH2
FR	2	SEM21014FR1 SEM21014FR2	SEM21028FR1 SEM21028FR2	SEM21062FR1 SEM21062FR2
DP (Depth A: 0-6")	2	SEM21014DPA1 SEM21014DPA2	SEM21028DPA1 SEM21028DPA2	SEM21062DPA1 SEM21062DPA2
DP (Depth B: 6-12")	2	SEM21014DPB1 SEM21014DPB2	SEM21028DPB1 SEM21028DPB2	SEM21062DPB1 SEM21062DPB2
DP (Depth C: 12-18")	2	SEM21014DPC1 SEM21014DPC2	SEM21028DPC1 SEM21028DPC2	SEM21062DPC1 SEM21062DPC2

All samples collected after the 14- and 62-day curing period were analyzed for the following analytical parameters:

- pH
- Chloride, Resistivity, Sulfate, Sulfide
- TAL-Metals
- TCL-BNA+20
- TCL-PCB

- TCL-Pest
- TOC
- TPHC
- Dioxin/Furans

In addition to the above analytical parameters, samples collected after the 28-day curing period were analyzed for the following:

- MEP Leaching Test (Modified in accordance with NJDEP protocol)

The TCL-VOC+10 analysis was not conducted on any of the pilot treated Stratus samples due to general non-detection of volatile compounds during the untreated material characterization.

The following reference photographs are included in Appendix A-1 for Section 5.8.4:

Photograph 5-45:	Sampling of the Pilot-Scale Treated Stratus Material Cured under "RT" Conditions
Photograph 5-46:	Sampling of the Pilot-Scale Treated Stratus Material Cured under "DRY" Conditions
Photograph 5-47:	Sampling of the Pilot-Scale Treated Stratus Material Cured under "RH > 95%" Conditions
Photograph 5-48:	Sampling of the Pilot-Scale Treated Stratus Material Cured under "DP" Conditions
Photograph 5-49:	Sample Core from the Pilot-Scale Treated Stratus Material Cured under "DP" Conditions
Photograph 5-50:	Transfer of the Sample Cores to the Bench-Top Blender for Field Compositing
Photograph 5-51:	Field Compositing of the Sample Cores in a Bench-Top Blender Prior to Submission to Analytical Laboratory

5.9 Chemical Analysis

BEM selected target parameters and methodologies for chemical analysis during the pilot study in accordance with the October 1997 NJDEP Technical Manual, and November 1998 NJDEP document entitled "Guidance for Sediment Quality Evaluations." The NJDEP guidance documents were used to determine priority contaminants for sediment quality evaluation, acceptable detection limits and general quality control procedures. The parameters, methodologies, and acceptable detection limits for chemical analysis were previously presented in BEM's final Pilot Study Workplan dated 03 May 2000. In general, all field procedures related to chemical analysis were conducted in accordance with the detailed Quality Assurance Project Plan (QAPP) prepared by BEM and submitted to NJMR in May 2001.

5.9.1 Sediment and Water Analyses

All chemical analyses (except dioxins/furans analysis) for sediment (untreated and treated) and aqueous samples were performed by Accutest Laboratories (Accutest) of Dayton, New Jersey, under a subcontractor agreement with BEM. The dioxins/furans analysis for all samples was subcontracted by Accutest Laboratories to Paradigm Analytical Laboratories, Inc. of Wilmington, North Carolina.

In general, EPA's SW846 analytical methods were used during this pilot study. Table 5-16 provides a list of target parameters and analytical methodologies used for the chemical analysis.

Table 5-16: Summary of Chemical Testing Parameters and Methodologies

Matrix	Parameter	Methodologies
Sediment/Aqueous	pH	SW846 9045C
Sediment	Sulfate	SW846 9056
Sediment	Sulfide	SW846 9030B
Sediment	Chloride	SW846 9056
Sediment	Resistivity	SM18 2510A
Sediment	Total Organic Carbon (TOC)	SW846 9060
Sediment/Aqueous	Volatile Organic Carbon (VOC)	SW846 8260B
Sediment/Aqueous	Semi-Volatile Organic Carbon (SVOC)	SW846 3520C/8270C with GPC
Sediment/Aqueous	Pesticides	SW846 3520C/8081A
Sediment/Aqueous	PCBs (as Aroclors)	SW846 3520A/8082
Sediment/Aqueous	TAL/Metals	SW846 6010/7000
Sediment/Aqueous	Dioxins/Furans Congeners	SW846 8290
Sediment/Aqueous	Total Petroleum Hydrocarbons (TPHC)	SW846 3545/E418.1 (Modified)
Sediment	Multiple Extraction Procedure (MEP) Leaching Test[a]	SW846 1320 (Modified in accordance with NJDEP protocol.)

[a] MEP Leaching Test used in this study is an NJDEP modified version of the EPA SW846 1320 method. The procedure consists of seven (7) extraction steps and subsequent leachate chemical analysis on the same sample aliquot using a standard TCLP procedure (EPA SW846 1311). In the NJDEP modified version, dioxins/furans analysis is performed only on the first (1st) and seventh (7th) extraction steps

The results of the Bulk Chemical Analysis and MEP leaching tests were compared to the chemical success criteria established for the pilot study and as presented in Section 4.2.1.

5.9.2 Quality Assurance and Quality Control (QA/QC)

Detailed analytical data quality assurance and control methods followed during this pilot study were presented in BEM's QAPP, previously submitted to NJMR in May 2001. The quality assurance program provided steps for ensuring traceable documentation of project records, technically accurate reports and documentation, records of proper equipment calibrations used, and adherence to the intended scope of work. The following methods were generally used to achieve the necessary levels of control to produce data of known and desired quality:

- Collection of field triplicate/duplicate samples, and calculation of relative standard deviation (RSD) or relative percent difference (RPD) to ensure use of analytical data with values < 20%;
- Collection of equipment blanks, and tap water samples for chemical analysis;
- Collection of quality assurance and quality control field samples (matrix spike [MS] and matrix spike duplicate [MSD]) to evaluate the accuracy and precision of the analytical measurement system;
- Chemical analysis of method blanks, matrix spikes, matrix spike duplicate samples, and surrogate recovery during sample analysis at the analytical laboratory;
- Validation of all chemical data by an independent data validator.

The following further details the specific QA/QC procedures used during the pilot study:

5.9.2.1 Triplicate and Duplicate Samples

The initial Stratus material chemical characterization was performed with 5-part composite samples collected in triplicate and submitted to the laboratory (i.e. SEU-1, SEU-2, and SEU-3). BEM calculated the average and relative standard deviation (RSD) of these results. The average was used for comparison with subsequent analyses. The RSD was used to identify compounds or parameters that the laboratory had difficulty quantifying with a satisfactory degree of precision. Results exceeding 20% RSD were considered unsatisfactory and treated as approximate results.

All subsequent untreated and treated Stratus as well as Tremley Point material samples were collected in duplicate. In these cases, the average was calculated and used to compare with other data. The relative percent difference (RPD) was also calculated to evaluate the precision performance of the laboratory analytical methods. The RPD was used to identify compounds or parameters that the laboratory had difficulty quantifying with a satisfactory degree of precision. Results exceeding 20% RPD were considered unsatisfactory and the treated as approximate results.

5.9.2.2 Equipment Blanks

In addition, BEM collected equipment blanks to determine if equipment decontamination procedures had been sufficient. Equipment blanks were obtained by pouring distilled water over/through decontaminated sample collection equipment (auger, spatula, etc.) and then collecting it in the appropriate containers for chemical analysis. Equipment blanks were collected from the several sampling and treatment devices to provide a representative indication of the success of field cleaning procedures. Equipment blanks were submitted for randomly selected sampling events of the pilot treatment study.

5.9.2.3 Laboratory Tap Water Analysis

Chemical analyses were also performed on the tap water from the laboratory at the Rutgers CAIT facility. These analyses were done in order to ensure that the use of the tap water for re-hydrating the untreated material and use throughout the bench and pilot study did not impact the levels of contaminants in the material.

5.9.2.4 Field Control Samples

In addition to the triplicate/duplicate samples and equipment blanks, field QA/QC techniques consisted of MS and MSD sample collection.

BEM collected the following field samples for the MS/MSD analysis during one of the pilot treatment trains:

- SEM21014RT1;
- SEM21028RT1;
- SEM21062RT1.

5.9.2.5 Lab Control Samples

The laboratory QC included the use of method blanks, matrix spikes (MS) and matrix spike duplicates (MSD), and surrogate recoveries.

The purpose of the method blank was to ensure that no contaminants were introduced by the glassware, reagents, standards, personnel, or sample preparation environment. One method blank was prepared by the analytical laboratory for every twenty samples collected by BEM.

The MS was used to evaluate the effect of the sample matrix on the accuracy of the analysis. The MS analysis included the measurement of a known concentration of an analyte used as a spike for a lab sample, and subsequent confirmation of the concentration through chemical analysis, and expressed as percent recovery.

The MSD samples were divided into two separate aliquots, each one spiked with known concentrations of analytes, along with two spiked aliquots processed separately. The results from the MSD, expressed as relative percent difference (RPD) and percent recovery, were used to determine the effects of the matrix on the precision and accuracy of the analysis. One set of MS/MSD tests was conducted by the analytical laboratory for every 20 samples. Surrogate standards were added to each organic sample, which required GC/MS analysis for VOCs and SVOCs, in accordance with the particular method being utilized. Surrogate recoveries were required to meet the method acceptance criteria before the analytical data was released.

5.9.2.6 Independent Data Validation

Each laboratory analyst reviewed the quality of his/her work based on an established set of guidelines. The QC data validation criteria set forth in the corresponding methods were used to evaluate the data. Once the data were transferred to the laboratory sample management system, the data was reviewed by the Group Leader and marked on the sample management system as being verified. The lab analyst reviewed all data including quality control information prior to verifying the data. Data package deliverables were requested and the laboratory completed the appropriate forms summarizing the quality control information. Copies of all raw data (instrument printouts, spectra, chromatograms, etc.) were transferred to the Data Packages Group. The Data Packages Group combined the information from the various analytical groups and the analytical reports from the laboratory sample management system into one package. This package was reviewed by the Quality Assurance Department for conformance with standard operating procedures (SOPs) to ensure that all QC goals were met. Any analytical problems were discussed in the case narrative, which was also included with the data package deliverables to BEM.

Following data validation by the laboratory, BEM conducted follow up data review. All analytical data submitted by analytical laboratories and reviewed by BEM for completeness, was validated by an independent data validator, Ms. Julie Smith, retained by BEM for this project. All data was reviewed in accordance with the appropriate regulatory guidelines and/or associated analytical methodology. If required, the data was qualified, negated, or rejected according to applicable validation protocols and professional judgement. In addition, BEM also requested the independent data validator, Ms. Julie Smith to prepare QA/QC Compliance reports for validated data packages selected at random, in order to document that the QA/QC procedures were being followed. Copies of the QA/QC Compliance reports prepared as part of this study, and previously provided to OMR, are included in Appendix A-3.

5.10 Geotechnical Testing

The geoetechnical testing of the untreated and Georemediation^{TM} treated material was performed under the supervision of Dr. Ali Maher of Soiltek, Inc. at the Rutgers University Geotechnical and Beneficial Reuse Laboratories as part of the Center for Advanced Infrastructure and Transportation (CAIT) center in Piscataway, NJ. The geotechnical testing was performed during this pilot study to evaluate the suitability of the Georemediation^{TM} treatment sediments for the anticipated beneficial use applications previously discussed in Section 4.2.

Geotechnical laboratory testing was performed on the untreated Stratus material and material treated with the Georemediation^{TM} under the three (3) treatment conditions described below:

- Mix 1: Stratus material treated using Georemediation^{TM} Mix 1 at 10% loading by wet weight of untreated sediments, applied as a reagent slurry using 1:1 reagent to water ratio;
- Mix 2 [RT]: Stratus material treated using Georemediation^{TM} Mix 2 at 10% loading by wet weight of untreated sediments, applied as a reagent slurry using 1:1 reagent to water ratio [same as **"RT"** condition];
- Mix 2 [DRY]: Stratus material treated using Georemediation^{TM} Mix 2 at 10% by wet weight of untreated sediments, applied as a dry reagent powder (without any additional water) [same as **"DRY"** condition].

The treatment of the material used for geotechnical testing was performed with the Georemediation^{TM} reagents at the pilot scale following the procedures detailed in Section 5.9. Separate pilot treatment procedures were followed for the Georemediation^{TM} Mix 2 added to the untreated material in slurry and the dry powder form (previously identified as **"RT"** and **"DRY"** conditions). After the treatment, custody of the samples was turned over to Mr. Tom Bennert of Rutgers-CAIT for geotechnical testing under the overall supervision of Dr. Ali Maher.

Table 5-17 summarizes the Geotechnical tests, testing methodologies, # of tests, and the purpose of each test for the untreated and treated Stratus material.

Table 5-17: Summary of Geotechnical Testing Parameters, Methodologis, and Purpose of the Tests Performed

Parameter	Methodology	Purpose
Tests Conducted on the Untreated Stratus Material		
Percent Moisture	ASTM D 2216	To aid in characterizing the material and determining the degree of solidification required prior to reuse
Specific Gravity	ASTM D 854-83	To determine the relative density of the material in reference to standard water density
Grain-Size Analysis	ASTM D 421/422	To determine the particle-size distribution of the material
Atterberg Limits	ASTM D 4318	To define the consistency of the material as a function of its water content
Additional Tests Conducted on Georemediation^{TM} Treated Material		
Solidification	N/A	To determine the time period required to achieve target moisture content resulting in 90% of the

Parameter	Methodology	Purpose
		maximum dry density of the material
Modified Compaction	ASTM D 1557/T 180	To determine the relationship between moisture content and density of the material for the purpose of compaction levels required prior to placement
California Bearing Ratio (CBR)	ASTM D 1883	To determine the thickness and value of the material as a sub-base or sub-grade material
Unconfined Compression	ASTM D 2166	To determine the strength of an unconfined and unconsolidated material
Swell Potential	ASTM D 4546	To determine swelling potential and swelling pressure of the material
Collapse Potential	ASTM D 5333	To determine deformation characteristics of a compacted and constant load bearing material after its inundated with water
Permeability	ASTM D 5084	To determine the hydraulic conductivity of the compacted and saturated material
Resilient Modulus	AASHTO T 274-82	To determine plastic deformation of the material under simulated traffic conditions
Freeze/Thaw Test	ASTM D 560	To determine how material behaves or degrades after repeated freeze-thaw cycles

Table 5-18 summarizes the number of geotechnical tests performed on the untreated and treated Stratus material as part of the pilot study.

Table 5-18: Geotechnical Testing Plan for Untreated and Treated Stratus Material

Parameter	Methodology	Untreated	Treated Samples		
			Mix 1	Mix 2 [RT]	Mix 2 [DRY]
Percent Moisture	ASTM D 2216	3	3	3	3
Grain-Size Analysis	ASTM D 421/422	3	3	3	3
Atterberg Limits	ASTM D 4318	3	3	3	3
Solidification	N/A		3	3	3
Specific Gravity	ASTM D 854-83	3	3	3	3
Modified Compaction	ASTM D 1557/T 180		3	3	3
California Bearing Ratio (CBR)	ASTM D 1883		3	3	3
Unconfined Compression	ASTM D 2166		3	3	3
Swell Potential	ASTM D 4546		3	3	3
Collapse Potential	ASTM D 5333		3	3	3
Permeability	ASTM D 5084		3	3	3
Resilient Modulus	AASHTO T 274-82		3	3	3
Freeze/Thaw Test	ASTM D 560		3	3	3

5.11 Air Emissions Testing

BEM conducted air emissions testing during one of the pilot treatment and curing trains (RT) in order to evaluate the potential for unacceptable emissions of certain contaminants. For this purpose, specific air emission analyses were performed to evaluate the emissions potential of the following class of contaminants:

- Volatile Organic Compounds (VOCs);
- Pesticides and Polychlorinated Biphenyls (PCBs);
- Polycyclic Aromatic Hydrocarbons (PAHs)/Semi-Volatile Organic compounds (SVOCs);
- metals.

The air emissions testing was conducted during the Georemediation^{TM} treatment as well as several days into the curing stage to determine the time period for the occurrence of potential maximum air emissions.

All air samples collected by BEM during the pilot study were analyzed (except for metals) by Air Toxics Ltd. (Air Toxics) of Folsom, California. The metals analyses were sub-contracted by Air Toxics to Wilson-Walker Environmental, Inc. of Westerville, Ohio.

5.11.1 Air Emissions Sampling – First Round

An initial air emissions sampling was performed during the Georemediation^{TM} pilot treatment and curing of the Stratus material on 20 July 2001. The pilot treatment of the Stratus material was performed using Georemdiation^{TM} Mix 2 at 10% loading by wet weight of approximately 162 lbs of untreated material, applied as a 1:1 reagent to water slurry (same as "RT" condition).

The first set of air samples was collected when the Georemediation^{TM} Mix 2 slurry was added to the Stratus sediment in the rotating 3-cubic feet cement mixer. Once the Georemediation^{TM} Mix 2 slurry was added, a Summa canister was used to take a grab sample for VOC analysis at the open end of the cement mixer. In addition, four low-flow sample pumps were used to collect air samples for 20 minutes for SVOCs, metals, mercury, and Pest/PCBs during the 20-minute mixing.

The treated Stratus material was then transferred into a 24"x 36"x6" pan for curing. The curing pan was placed in close proximity to the laboratory exhaust hood. Air samples were collected during the curing process by sampling approximately 4" above the surface of the open curing pan. All sampling equipment were placed between the curing pan and the exhaust hood to capture the maximum possible air emissions from the curing material. Summa canisters were used to collect grab samples, and four low-flow sample pumps were used to collect 4-hour samples starting at 0 hour, 4 hours, 8 hours, 24 hours and 48 hours after curing began at room temperature.

Table 5-19 provides the sample IDs, sampling intervals, sampling duration, sampling parameters, and analytical methodologies for the first round of air emissions testing.

Table 5-19: First Round Air Emission Monitoring Sample IDs, Times, Duration, Parameters and Methodologies

Sample ID(s)	Sample Interval	Sample Duration	Parameter	Analytical Methodology
SM2A1-15	Mixing (1)	Grab	VOC	TO-15
SM2A1-13		20 minutes	SVOC	TO-13
SM2A1-10		20 minutes	Pest/PCB	TO-10
SM2A1-Met		20 minutes	Metals	NIOSH 7300
SM2A1-Hg		20 minutes	Mercury	NIOSH 6009
SM2A(2-6)-15	0 hr (2)	Grab	VOC	TO-15
SM2A(2-6)-13	4 hr (3)	4 hour	SVOC	TO-13
SM2A(2-6)-10	8 hr (4)	4 hour	Pest/PCB	TO-10
SM2A(2-6)-Met	24 hr (5)	4 hour	Metals	NIOSH 7300
SM2A(2-6)-Hg	48 hr (6)	4 hour	Mercury	NIOSH 6009

A modified EPA Method TO-15 procedure was used to determine VOCs concentrations in grab samples collected in six-liter Summa canisters. This method uses gas chromatography/mass spectrometry (GC/MS) instrumentation to provide a standard EPA Target Compound List (TCL) of VOCs in addition to ten tentatively identified compounds (TICs).

A modified EPA Method TO-10 procedure was used to determine the concentrations of pesticides and PCBs in the samples collected using a low-flow sample pump. The samples were collected over a four-hour sampling period on a polyurethane foam (PUF) sample cartridge. The samples were then analyzed using gas chromatographic/multi-detector detection (GC/ECD) instrumentation to quantify pesticide and Aroclor concentration data.

A modified EPA Method TO-13 procedure was used to analyze for PAHs [or semi-volatile organic compounds (SVOCs)] and up to fifteen TICs. The samples were collected over a four-hour sampling period using a low-flow sample pump. The samples were collected on a PUF/XAD cartridge in a volatile organic sampling train (VOST) tube and analyzed using GC/MS.

NIOSH method 7300 was used to analyze metals in the samples collected using a low-flow sample pump. The samples were collected on a cellulose ester membrane filter over a four-hour sampling period. The samples were analyzed using atomic emission spectroscopy. The metals analyses did not include analysis for mercury and therefore NIOSH method 6009 was used to determine mercury concentrations. The samples were collected over a four-hour sampling period on a solid sorbent tube using a low-flow sample pump. The samples were analyzed using atomic absorption.

5.11.2 Air Emissions Testing – Second Round

The initial round of air sampling was conducted for the duration of 48 hours. However, as presented in Section 6.5.1, the emission results of this sampling did not indicate the achievement of steady-state conditions, with maximum VOCs emissions anticipated beyond 48-hour curing period. Therefore, a second round of air sampling for a longer curing period was deemed necessary for VOCs emissions.

On 27 August 2001, BEM conducted the second round of air emissions sampling for VOCs using the modified EPA method TO-15. BEM treated approximately 162 lbs of Stratus material with Georemediation^{TM} Mix 2 at 10% loading by wet weight of untreated material, applied as a 1:1 reagent to water slurry (same as "RT" condition).

The first set of air samples was collected when the Georemediation^{TM} Mix 2 slurry was added to the Stratus sediment in the rotating 3 cubic feet cement mixer. Once the Georemediation^{TM} Mix 2 slurry was added, a Summa canister was used to take a grab sample for VOCs analysis at the open end of the cement mixer. The treated Stratus material was then transferred into a 24"x36"x6" plastic pan for curing. The curing pan was placed in close proximity to the laboratory exhaust hood. Air samples were collected during the curing process by sampling approximately 4" above the surface of the open curing pans. All sampling equipment were placed between the curing pan and the exhaust hood to capture the maximum possible air emissions from the curing material. Summa canisters were used to collect grab samples at 0 hour, 4 hours, 8 hours, 24 hours, 48 hours, 72 hours, and 96 hours after curing began at room temperature.

Table 5-20 provides the sample IDs, sampling intervals, sampling duration, sampling parameters, and methodologies for the second round of air emissions testing.

Table 5-20: Second Round Air Emission Monitoring Sample IDs, Times, Duration, Parameters and Methodologies

Sample ID(s)	Sample Interval	Sample Duration	Parameter	Methodology
SM2A7-15 SM2A(8-15)-15	Mixing (7) 0 hr (8) 4 hr (9) 8 hr (10) 24 hr (11) 36 hr (12) 48 hr (13) 72 hr (14) 96 hr (15)	Grab	VOC	TO-15

5.12 Mechanical Dewatering Test

On 30 July 2001 BEM provided untreated and Georemediation^{TM} treated samples to Komline-Sanderson, Peapack, NJ for evaluating technologies for the potential dewatering of the material before and/or after treatment during full-scale operations. The tests were modeled after Komline-Sanderson's GRS-2 Kompress® Belt Filter Press technology.

Approximately 10-gallons of samples (untreated and treated) were provided to Komline-Sanderson in 5-gallon buckets for the dewatering tests. The treated sample was mixed with Georemediation^{TM} reagent Mix 2 at 10% by wet weight of the sediment, and slurried with 1:1 reagent to water ratio, prior to mixing (same as "RT" condition). An application questionnaire and Material Safety Data Sheets (MSDS) issued by Komline-Sanderson were prepared and submitted by BEM along with the samples. The questionnaire included information related to the objectives, feed characteristics, desired process rates and end-product characteristics of the dewatered material.

Two (2) polymers, Cytec, Inc.'s 4518 (high charge and high molecular weight cationic emulsion) and Cytec, Inc.'s A-1883 (high molecular weight anionic emulsion) were tested with the untreated sample dewatering. No additives were used with the treated sample because the material was largely solidified and passed the paint filter test (i.e. showed no free water) even prior to dewatering.

The results and the conclusions of the mechanical dewatering tests are presented in Section 6.5.2.

6.0 RESULTS AND DISCUSSION

The following sub-sections present the results and discussion of the tests and analyses performed as part of the work outlined in Section 5.0. The results include the chemical analysis to determine the chemical effectiveness, geotechnical testing to determine the beneficial use potential of the Georemediation™ treated dredged material, and the air emissions and mechanical dewatering tests.

6.1 Chemical Analysis

The following sections present the results of the analytical testing performed on the untreated (raw) and Georemediation™ treated samples (under various conditions) for both Stratus and Tremley Point material. Although, complete validated analytical results for all samples collected during this pilot study are included in Appendix B, results of some of the target parameters are included in the discussions that follow.

6.1.1 Source Material Characterization

6.1.1.1 Stratus Material Characterization

The results of the triplicate composite samples (SEU1, SEU2, and SEU3) collected during initial characterization sampling, and duplicate composite samples (SEU41 and SEU42) collected during subsequent characterization sampling are presented in Appendix B-1. The data tables include the average results and relative standard deviation (RSD) or relative percent different (RPD) [as applicable], and a comparison with the NJDEP RDCSCC.

The average results of the initial characterization sampling conducted in October 2000 (SEU Avg.) did not indicate any exceedances above the most stringent NJDEP RDCSCC applicable to upland placement of the material. However, the subsequent characterization sampling conducted in August 2001 (SEU4 Avg.) showed low level exceedances of certain PAH compounds above the NJDEP RDCSCC. Although, there was a wide difference in PAHs results during two separate characterization analyses, as acceptable RSD or RPD (< 20%) was generally observed for all contaminant groups during both sampling events (Appendix B-1). For all practical purposes, the results of all bench-scale and pilot-scale treatment are compared to the average subsequent characterization results (SEU4 Avg.) of the Stratus material.

Table 6-1 provides average results of the subsequent characterization of the Stratus material, for selected target parameters for each class of compounds analyzed, along with a comparison with the NJDEP RDCSCC.

Table 6-1: Untreated Stratus Material Characterization Results

Analyte	NJDEP RDCSCC (mg/kg)	SEU4 Avg. (mg/kg) [b]
General Chemistry		
TPHCs	10,000	237
TOC	N/A	3.54%
Total Solids	N/A	43.2%
VOCs		
None Detected or Exceeded		

Analyte	NJDEP RDCSCC (mg/kg)	SEU4 Avg. (mg/kg) [b]
SVOCs		
Total PAHs	N/A	9.62
Benzo(a)anthracene	0.9	0.84
Benzo(a)pyrene	0.66	0.93
Benzo(b)fluoranthene	0.9	1.3
Pesticides/PCBs		
Dieldrin	0.042	N/A
Aroclor 1248	0.49	N/A
Aroclor 1260	0.49	N/A
Dioxins/Furans		
Total TEQ	50 ppt[a]	212 ppt
Metals		
Arsenic	20	14.0
Lead	400	137

why?

[a] Comparison criteria for dioxins (total TEQ) are based on 1997 Agency for Toxic Substances and Disease Registry (ATSDR) Interim Policy Guidelines

[b] Shaded cells indicate exceedances above the applicable regulatory cleanup criteria

N/A – Not Available

The results of the subsequent characterization sampling conducted in August 2001 (SEU4 Avg.) showed low level exceedances of certain PAH compounds above the NJDEP RDCSCC. The dioxins/furans (total TEQ) results indicate notable exceedance (> 4 times) above the ATSDR guidance level of 50 ppt for unrestricted use.

In addition to the Bulk Chemical Analysis results, Leaching analysis results from the NJDEP modified Multiple Extraction Procedure (MEP) [SW846 1320] were obtained during the subsequent characterization of the Stratus material. Duplicate untreated Stratus samples (SEU51 and SEU52) were extracted seven (7) times (L1 through L7) and analyzed for target parameters previously listed in Section 5.10. As per the NJDEP modified MEP method (SW846 1320), the leachate from only the first (L1) and seventh (L7) were analyzed for dioxin/furans. The complete results of the MEP analysis of the untreated Stratus material samples are provided in Appendix B-2.

Table 6-2 presents a summary of selected parameters that exceeded the NJDEP Groundwater Quality Standards (GWQS) during one or more of the extraction steps.

Table 6-2: Untreated Stratus Material MEP Leaching Test Results

Parameter	NJDEP GWQS (µg/l)	Stratus Untreated (SEU) MEP Results (µg/l)[a]						
		L1	L2	L3	L4	L5	L6	L7
SVOCs								
(No Exceedances)	N/A							
Pesticides/PCBs								

Parameter	NJDEP GWQS (µg/l)	Stratus Untreated (SEU) MEP Results (µg/l)[a]						
		L1	L2	L3	L4	L5	L6	L7
alpha BHC	0.02	0.94	0.74	0.56	0.07	0.73	0.46	0.23
gamma BHC (Lindane)	0.2	0.61	0.19	0.29	0.017	0.35	0.19	0.091
Dieldrin	0.03	0.02	0.02	0.032	0.012	0.10	0.051	0.048
Dioxins/Furans								
(No Exceedances) [L1 & L7 only]	N/A							
Metals (heavy)								
Arsenic	8	4.7	7.6	22.4	14.5	14.1	5.0	4.5
Lead	10	10.2	1.3	72.3	30.1	29.1	24.4	20.8

[a] Shaded cells indicate exceedances above the NJDEP GWQS

N/A – Not Applicable

) where are the #s?

no PCBs?

The MEP leaching results indicate that the untreated Stratus material may likely impact the groundwater designated for potable water supply. The results also indicate higher leaching of contaminants (especially metals) during L3 to L6 leaching steps.

Although, exceedances of certain pesticide compounds above the NJDEP GWQS were noted, none of these pesticide compounds (except Dieldrin) were detected in the untreated samples during pesticides analysis.

6.1.1.2 Tremley Point Material Characterization

The complete results of the duplicate composite samples (TPU-1 and TPU-2) collected in April 2001 are presented in Appendix B-3. The data tables in Appendix B-3 also include the average results, relative percent different (RPD), and a comparison with the NJDEP RDCSCC.

Table 6-3 provides average Tremley Point characterization results (TPU Avg.) of selected target parameters for each class of compounds analyzed, along with a comparison with the NJDEP RDCSCC.

Table 6-3: Tremley Point Material Characterization Results (Selected Target Parameters)

Analyte	NJDEP RDCSCC (mg/kg)	TPU Avg. (mg/kg)
General Chemistry		
TPHCs	10,000	367
TOC	N/A	4.67%
Total Solids	N/A	34%
VOCs		
Benzene	3	0.016
Toluene	1,000	0.074
Ethylbenzene	1,000	0.014
Xylene (total)	410	0.037
SVOCs		

Analyte	NJDEP RDCSCC (mg/kg)	TPU Avg. (mg/kg)
Total PAHs	N/A	5.4
Benzo(a)pyrene	0.66	0.423
Benzo(a)anthracene	0.9	0.415
Benzo(b)fluoranthene	0.9	0.380
Pesticides/PCBs		
4,4'-DDD	3	0.185
4,4'-DDE	2	0.082
4,4'-DDT	2	1.165
Aroclor 1248	0.49	0.38
Aroclor 1254	0.49	0.49
Aroclor 1260	0.49	0.31
Dioxins/Furans		
Total TEQ	50 ppt[a]	140 ppt
Metals		
Arsenic	20	27.6
Mercury	14	6.2
Lead	400	270

[a] Comparison criteria for dioxins (total TEQ) are based on 1997 Agency for Toxic Substances and Disease Registry (ATSDR) Interim Policy Guidelines

[b] Shaded cells indicate exceedances above the applicable regulatory cleanup criteria

N/A – Not Available

Tremley Point material characterization results indicate a more organic material (4.67% TOC) as compared to Stratus material (3.54% TOC). However, Tremley Point material shows a lower concentration of total PAHs (5.4 mg/kg) as compared to Stratus material (9.6 mg/kg). The Pesticides/PCBs results indicate a higher number of detects and concentrations of certain compounds in Tremley Point material as compared to the Stratus material. The dioxins/furans concentration (TEQ) in the Tremley Point material was detected at a lower concentration (140 ppt) as compared to Stratus material (202 ppt).

6.1.2 Tap water Chemical Analysis

Chemical analyses were performed on the tap water from the Rutgers laboratory to ensure that the use of the tap water for re-hydrating the untreated material and use throughout the study did not introduce additional contaminants into the media. The chemical data summary tables for the tap water analyses are provided in Appendix B-4. The results of the analyses were compared to the NJDEP GWQS, and no exceedances were found for the parameters analyzed.

6.1.3 Bench-Scale Treatment Results

Bench-scale treatment was conducted on both Stratus and Tremley Point material following the procedures detailed in Section 5.8, to determine the most chemically effective Georemediation™ mix type and loading rate. The following sections present the detailed results of the bench-scale treatment testing and comparison with the untreated results for both Stratus and Tremley Point material.

6.1.3.1 Stratus Material Bench-Scale Results – Round 1

The first round of bench-scale testing on the Stratus material was conducted in December 2000 based on the results of the initial Stratus material characterization. Since the initial characterization results (SEU Avg.) showed no exceedances above the NJDEP RDCSCC for any of the contaminant groups (except dioxins/furans), none of these contaminant groups were analyzed for bench-scale treated sediments. However, since dioxins/furans concentration was above the ATSDR guidance value of 50 ppt, only dioxins/furans analysis was used to determine an effective Georemediation™ mix type and loading rate for the Stratus material.

Two separate Georemediation™ mixes (Mix 1 and Mix 2) were applied at two different loadings (10% and 20% by wet weight of sediments) in a slurry form with 1:1 reagent to water ratio (by weight). All Stratus samples treated at the bench-scale were analyzed in duplicate after a 14-day curing period at room temperature. The analytical data tables providing detailed dioxins/furans results of these samples are presented in Appendix B-5.

Table 6-4 provides a comparative analysis of the average dioxin concentrations (total TEQ) of the untreated and bench-scale treated Stratus samples.

are you sure?

Table 6-4: Stratus Material Bench-Scale Treatment Results After 14-Day Curing Period – Round 1 (Mix 1 and Mix 2)

Analyte[a]	ATSDR Criteria (ppt)	Untreated Results (SEU 4 Avg.) (ppt)[c]	Bench-Scale Treated Results (mg/Kg)[b]				Bench-Scale Treated Results (% Reduction)			
			Mix 1		Mix 2		Mix 1		Mix 2	
			10%	20%	10%	20%	10%	20%	10%	20%
Dioxins/Furans										
Total TEQ	50 ppt[b]	▨ 212 ppt	28.65	36.00	11.27	▨ 59.80	86%	83%	95%	72%

[a] Only dioxins/furans analysis was performed since no other contaminants were detected above the chemical efficacy success criteria during the first round of Stratus material characterization (i.e. NJDEP RDCSCC)

[b] Comparison criteria for dioxins (total TEQ) are based on 1997 Agency for Toxic Substances and Disease Registry (ATSDR) Interim Policy Guidelines

[c] Shaded cells indicate exceedances above the applicable regulatory cleanup criteria

how can more reagent be worse?

As later discovered, the percent reductions for the dioxins/furans presented above in Table 6-4 were biased much higher due to inaccurate data provided by the analytical laboratory for the treated samples (as discussed in detail Section 6.3). However, these inaccuracies were only discovered after the data comparison and selection and implementation of the treatment conditions for the next stage (pilot treatment stage). Therefore, based on the bench-scale treatment results presented above, the following observations were made:

- Georemediation™ Mix 2 applied at a loading of 10% by wet weight of sediments, in a slurry form with 1:1 reagent to water ratio will likely be most effective in reducing the dioxin contamination;
- An increase in the reagent loading from 10% to 20% shows a decrease in the chemical effectiveness against the dioxin contamination, for both Mix 1 and Mix 2.

6.1.3.2 Tremley Point Material Bench-Scale Results – Round 1

Since all four (4) combinations of Georemediation™ mix type (Mix 1 and Mix 2) and loading rate (10% and 20%) used for Stratus bench-scale testing suggested significant reductions (70% to 94%) in total dioxin TEQ concentrations, the same mix types and loading rates were used for bench-scale testing for the Tremley Point material.

The laboratory procedures and methods used for bench-scale testing of Tremley Point material are detailed in Section 5.8. In order to accommodate the additional analytical testing for the Tremley Point material and minimize its impact on the pilot study budget, dioxin analysis was not performed on the bench-scale treated Tremley Point samples. The analytical data tables providing detailed results of the Tremley Point bench-scale treatment are presented in Appendix B-6.

Table 6-5 provides a comparative analysis of the average concentrations of selected target parameters from each class of compounds analyzed (except dioxins and VOCs) for the untreated and bench-scale treated Tremley Point samples.

Table 6-5: Tremley Point Material Bench-Scale Treatment Results After 14-Day Curing Period – Round 1 (Mix 1 and Mix 2)

Analyte[a]	NJDEP RDCSCC (mg/kg)	Untreated Results (Initial) (mg/kg)[b]	Bench-Scale Treated Results (mg/Kg)[b]				Bench-Scale Treated Results (% Reduction)			
			Mix 1		Mix 2		Mix 1		Mix 2	
			10 %	20 %	10 %[c]	20 %	10 %	20 %	10 %[c]	20 %
SVOCs										
Total PAHs	N/A	5.4	7.07	6.63	11.01 (3.1)	4.07	-31%	-23%	-104% (43%)	25%
Benzo(a)anthracene	0.9	0.415	0.495	0.459	0.864 (0.198)	0.327	-20%	-10%	-108% (52%)	21%
Benzo(a)pyrene	0.66	0.423	0.527	0.442	0.733 (0.186)	0.299	-25%	-4%	-73% (56%)	29%
Benzo(b)fluoranthene	0.9	0.380	0.636	0.484	0.772 (0.264)	0.392	-67%	-27%	-103% (31%)	-3%
Pesticides/PCBs										
4,4'-DDD	3	0.185	0.492	0.289	0.275	0.133	-166%	-56%	-48%	28%
4,4'-DDE	2	0.082	0.086	0.059	0.068	0.030	-5%	28%	18%	63%
4,4'-DDT	2	1.165	1.059	0.552	0.450	0.314	9%	53%	61%	73%
Aroclor 1248	0.49	0.380	0.314	0.350	0.103	0.162	18%	8%	73%	57%
Aroclor 1254	0.49	0.490	0.014	0.014	0.557	0.016	97%	97%	-14%	97%
Aroclor 1260	0.49	0.305	0.049	0.127	0.022	0.135	84%	58%	93%	56%
Metals										
Arsenic	20	27.6	20.2	19.2	27.3	26.2	27%	31%	1%	5%
Mercury	14	7	6	4.4	5.8	5.1	15%	38%	18%	28%
Lead	400	270	173	154	181	141	36%	43%	33%	48%

[a] No VOCs data is compared, as very low levels (<0.1 mg/kg) of individual VOC compounds were detected

[b] Shaded cells indicate exceedances above the applicable regulatory cleanup criteria

[c] Results presented in parenthesis ( ) for Mix 2 (10%) represent data from one of the duplicate samples. The second sample showed unusually higher concentrations of PAHs as compared to the first sample, with Relative Percent

Difference (RPD) ranging from 130% - 155%. The PAHs results of the second sample were inconsistent with the results of the untreated Tremley Point samples.

The results of the first round of bench-scale treatment on Tremley Point material indicate the following:

- Both Georemediation^{TM} mixes (Mix 1 and Mix 2) show positive reductions on low levels of Pesticides and PCBs. However, Mix 2 shows relatively higher percent reductions as compared to Mix 1;
- Mix 1 shows negative reductions on low levels of PAHs contaminants, thereby suggesting its ineffectiveness on the PAHs contamination;
- Mix 2 applied at 20% loading shows a positive reduction in PAHs contamination. However, average treated data (based on duplicate sampling) for Mix 2 applied at 10% loading shows significant negative reductions in the PAHs contaminants. An evaluation of the duplicate analysis indicates a significantly high relative percent difference (RPD) [130% to 150%] between the duplicate samples, with the PAHs concentrations in the second sample unusually higher (an order of magnitude higher in some cases). In addition, the PAHs results of the second sample were generally inconsistent with the results of the untreated Tremley Point material. The Mix 2 (10%) results presented in parenthesis indicate the positive percent reductions for PAHs based on the results of the first sample only;
- Both mixes (Mix 1 and Mix 2) show nominal reductions (primarily attributed to mass dilution) in the total metals contamination. However, Mix 2 appears to be rather ineffective in stabilizing arsenic (As) contamination as compared to Mix 1.

Overall results of both Stratus and Tremley Point bench-scale testing indicate a higher effectiveness of Mix 2 on decontaminating organic compounds (e.g. PAHs, PCBs, and dioxins/furans), as compared to Mix 1. Although, PAHs data for samples treated with Mix 2 at 10% loading showed unusually high RPD between duplicate samples, lower results from the first sample are assumed to be more accurate. This was later confirmed by analyzing the Mix 2 (10%) samples (as well as Mix 1 [10%] samples) after 52-day curing period. PAHs data for the 52-day curing period is summarized in Table 6-6.

The analytical data tables providing detailed results of the 52-day curing period samples are also presented in Appendix B-6.

Table 6-6: Tremley Point Material Bench-Scale Treatment Results After 52-Day Curing Period – Round 1 (Mix 1 and Mix 2)

Analyte[a]	NJDEP RDCSCC (mg/kg)	Untreated Results (Initial) (mg/kg)[b]	Bench-Scale Treated Results (mg/Kg)[b]		Bench-Scale Treated Results (% Reduction)	
			Mix 1	Mix 2	Mix 1	Mix 2
			10%	10%	10%	10%
SVOCs						
Total PAHs	N/A	5.4	10.58	5.76	-96%	-7%
Benzo(a)anthracene	0.9	0.415	0.811	0.430	-95%	-3%
Benzo(a)pyrene	0.66	0.423	0.749	0.400	-77%	5%
Benzo(b)fluoranthene	0.9	0.380	0.903	0.498	-138%	-31%
Metals						

Analyte[a]	NJDEP RDCSCC (mg/kg)	Untreated Results (Initial) (mg/kg)[b]	Bench-Scale Treated Results (mg/Kg)[b]		Bench-Scale Treated Results (% Reduction)	
			Mix 1	Mix 2	Mix 1	Mix 2
			10%	10%	10%	10%
Arsenic	20	27.6	22.9	26.95	17%	2%
Mercury	14	7	7.4	6.45	-6%	8%
Lead	400	270	205	203	24%	25%

[a] TPHCs and Metals were also analyzed for these samples

[b] Shaded cells indicate exceedances above the applicable regulatory cleanup criteria

6.1.3.3 Tremley Point Material Bench-Scale Results – Round 2

The results of the untreated Tremley Point material characterization show the presence of arsenic (As) at an average concentration of 27.6 mg/kg, above the NJDEP RDCSCC (20 mg/kg). Although, Mix 2 appeared to be more effective on the organic contaminants as compared to Mix 1, it was largely ineffective in reducing arsenic contamination below the NJDEP RDCSCC.

The second round of the Tremley Point material bench-scale testing was conducted to develop a Georemediation™ mix capable of reducing the total arsenic contamination below the target NJDEP RDCSCC. For this purpose, a new Georemediation™ mix (Mix 3) was applied to the Tremley Point material at 10% and 20% loading by wet weight of the sediments. However, the reagents in this testing were applied as a slurry with 1:1 ratio of reagent to a 0.6% Phosphoric acid (H_3PO_4) solution. The H_3PO_4 addition was made to enhance the precipitation and further immobilization of arsenic (As) in the sediment matrix.

Table 6-7 presents the results of the selected target parameters for the Mix 3 bench-scale testing on Tremley Point material. The complete analytical data table with appropriate qualifiers are provided in Appendix B-7.

Table 6-7: Tremley Point Material Bench-Scale Treatment Results After 28-Day Curing Period – Round 2 (Mix 3)

Analyte	NJDEP RDCSCC (mg/kg)	Untreated Results (Initial) (mg/kg)[a]	Bench-Scale Treated Results (mg/Kg)[a]		Bench-Scale Treated Results (% Reduction)	
			Mix 3	Mix 3	Mix 3	Mix 3
			10%	20%	10%	20%
SVOCs						
Total PAHs	N/A	5.4	3.39	4.02	37%	26%
Benzo(a)anthracene	0.9	0.415	0.275	0.38	34%	8%
Benzo(a)pyrene	0.66	0.423	0.26	0.30	39%	29%
Benzo(b)fluoranthene	0.9	0.380	0.325	0.375	14%	1%
Pesticides/PCBs						
4,4'-DDD	3	0.185	0.175	0.185	5%	0%
4,4'-DDE	2	0.082	0.0395	0.043	52%	48%
4,4'-DDT	2	1.165	0.435	0.365	63%	69%
Aroclor 1248	0.49	0.380	0.30	0.33	21%	13%
Aroclor 1254	0.49	0.490	0.014	0.014	97%	97%
Aroclor 1260	0.49	0.305	0.14	0.185	54%	39%

Analyte	NJDEP RDCSCC (mg/kg)	Untreated Results (Initial) (mg/kg)[a]	Bench-Scale Treated Results (mg/Kg)[a]		Bench-Scale Treated Results (% Reduction)	
			Mix 3	Mix 3	Mix 3	Mix 3
			10%	20%	10%	20%
Metals						
Arsenic	20	27.6	25.15	24.25	9%	12%
Mercury	14	7	5.7	4.7	19%	33%
Lead	400	270	166.50	138.00	38%	49%

[a] Shaded cells indicate exceedances above the applicable regulatory cleanup criteria

The results of the Mix 3 (slurried with 0.6% H_3PO_4 solution) bench-scale treatment of Tremley Point material did not show any marked improvement in the total reduction of the metal contaminants. Specifically Mix 3 treatment was not successful in reducing the arsenic (As) levels below the NJDEP RDCSCC of 20 mg/kg. However, Mix 3 showed consistent positive reductions in the organic contaminants at low levels (i.e. PAHs, Pesticides, and PCBs).

unable to reduce dioxin sufficiently

6.1.3.4 Stratus Material Bench-Scale Results – Round 2

The second round of bench-scale testing on the Stratus material was conducted subsequent to the review of the pilot treatment results using the previously selected Georemediation^{TM} Mix 2, as presented in Section 6.1.4. This additional bench-scale testing was performed to address the following issues identified with the Mix 2 used at the pilot treatment level (Reference results in Section 6.1.5):

- An increase in the total concentration of arsenic (As) in the material treated using Georemediation^{TM} Mix 2 and Mix 3;
- Leaching of the arsenic (As) and lead (Pb) above the NJDEP GWQS during the MEP test on the treated and cured (28-days) material;
- Ineffectiveness of the Georemediation^{TM} Mix 2 in reducing the dioxins/furans (total TEQ) concentrations below the chemical decontamination success criteria of 50 ppt (ATSDR guidance value) during the pilot treatment stage.

Table 6-8 presents the results (arsenic, lead, and dioxins/furans [total TEQ]) of the Stratus material treated using Georemediation^{TM} Mix 4 and Mix 5, and sampled after a 14-day curing period. The complete analytical data table with appropriate qualifiers are provided in Appendix B-8.

Table 6-8: Stratus Material Bench-Scale Treatment Results After 14-Day Curing Period – Round 2 (Mix 4 and Mix 5)

Analyte	NJDEP RDCSCC (mg/kg)	Untreated Results (Initial) (mg/kg)[a,b]	Bench-Scale Treated Results (mg/Kg)[a]		Bench-Scale Treated Results (% Reduction)	
			Mix 4	Mix 5	Mix 4	Mix 5
			10%	10%	10%	10%
Metals						
Arsenic	20	14	12.4	12.3	11%	12%
Lead	400	137	114	111	17%	19%
Dioxins/Furans						

Analyte	**NJDEP RDCSCC (mg/kg)**	**Untreated Results (Initial) (mg/kg)[a,b]**	**Bench-Scale Treated Results (mg/Kg)[a]**		**Bench-Scale Treated Results (% Reduction)**	
			Mix 4	**Mix 5**	**Mix 4**	**Mix 5**
			10%	**10%**	**10%**	**10%**
Total TEQ	50 ppt	212 ppt	169	154	20%	27%

[a] Shaded cells indicate exceedances above the applicable regulatory cleanup criteria

[b] Untreated results (including dioxin/furan results) used here are based on the re-characterization of the Stratus material prior to the pilot treatment stage and may differ from the results of the initial characterization results

Table 6-9 presents the results of the MEP leaching test (arsenic and lead only) for the Stratus material treated during the second round bench-scale testing using Georemediation™ mix 4 and Mix 5, and cured for a 14-day period.

Table 6-9: Stratus Material Bench-Scale Treatment MEP Leaching Test Results - Round 2 (Mix 4 and Mix 5)

Parameter	NJDEP GWQS (µg/l)	Treated MEP Results (µg/l)[a]						
		L1	L2	L3	L4	L5	L6	L7
Material Treated using Mix 4 and Cured for a 14-day Period								
Metals (heavy)								
Arsenic	8	17.10	22.55	21.30	18.25	15.55	9.85	12.35
Lead	10	2.02	2.08	2.18	5.10	3.82	10.10	14.90
Material Treated using Mix 5 and Cured for a 14-day Period								
Metals (heavy)								
Arsenic	8	14.25	25.80	21.20	17.15	14.30	12.50	11.70
Lead	10	2.33	3.18	2.78	13.33	11.85	11.55	23.70

[a] Shaded cells indicate exceedances above the NJDEP GWQS

N/A – Not Applicable

The results of the second round of bench-scale treatment on the Stratus material indicate the following:

- No increase in the arsenic (As) concentration was observed in the material treated using both Mix 4 and Mix 5, as previously observed in the pilot treatment results using Mix 2;
- No significant reduction in the arsenic (As) and lead (Pb) contamination was observed in the material treated using Mix 4 and Mix 5, and may largely be attributed to dilution;
- No significant reduction in the dioxins/furans (TEQ) contamination was observed in the material treated using Mix 4 and Mix 5, and may largely be attributed to dilution;
- The MEP results indicate that both Mix 4 and Mix 5 are not able to reduce the leaching of arsenic (As) and lead (Pb) below the NJDEP GWQS in all seven (7) extraction steps. Although, the material was tested at the end of 14-day curing period as compared to 28-day curing period previously tested, both mixes appear to be largely unsuccessful in meeting the leachate success criteria.

6.1.3.5 Apparent Increase in Contaminant Levels after Treatment

A total of five (5) Georemediation™ reagent mixes (Mix 1 through Mix 5) were tested at the bench-scale level using Stratus and Tremley Point material, and a selected reagent mix (Mix 2) at the pilot scale level using the Stratus material. A comparison of the untreated and treated results of the organic (e.g. PAHs, pesticides, PCBs, dioxins) and metal contaminants show a varied chemical effectiveness of the Georemediation™ technology under various treatment and curing conditions. Although, Georemediation™ mixes used during the study were inorganic in nature, an increase in certain organic contaminant (e.g. PAHs) concentrations was observed after the treatment under some of the conditions. In certain cases, an increase in the metals concentrations was also observed after treatment.

The observations described above render a typical contaminant mass balance difficult for the Georemediation^{TM} decontamination process. BEM proposes further investigation into the following potential sources and/or reasons leading to such observations:

- Inherent variability of the contaminant concentrations in the sediment matrix, compounded by their presence at low levels; and,
- Variability introduced by the standard analytical procedures through inconsistent extraction (of organic contaminants) or digestion (of metal contaminants) of the sediments with low levels of contaminants.

In addition to the above plausible reasons, the Georemediation^{TM} decontamination mechanism itself may be the potential reason for increases in the contaminant levels detected after treatment. The Georemediation^{TM} treatment is based on the formation of new chemically reactive surfaces. The generation of these surfaces is initialized during the slurrying of the reagent with water, through generation of organophilic (alumino-silicate) smectite clay, metal oxyhdroxides, and mineral surfaces. While this process continues during and after the addition of reagent slurry to the contaminated sediments, likely dissolution or chemical weathering of the alumino-silicate clay fraction of the sediments itself takes place due to an alkaline environment that contains transition metal oxy-hydroxides. This potential chemical weathering or dissolution of the sediment surfaces may be partly responsible for exposing fractions of organic and metal contaminants previously unavailable during extractions for the chemical analysis. The dissolution step is then followed by the precipitation of the ions and chemical complexes, and further reorganization into three-dimensional crystalline structures, thereby generating ordered and highly reactive surfaces needed to complete the decontamination.

∴ no need to proceed with this any further!

Not practical on a large scale for low-level material

6.1.4 Pilot Treatment Results

The main objective of the pilot treatment stage of this study was to evaluate the chemical and geotechnical effectiveness of the selected Georemediation^{TM} mix type and loading rate, and to simulate anticipated treatment, operational, and curing conditions that may impact the effectiveness, and consequently, the economics of the Georemediation^{TM} treatment at demonstration or full-scale operation. The following summarizes the difference between the bench-scale treatment and pilot treatment stage of this pilot study:

- Pilot treatment was conducted strictly on Stratus material, using a selected Georemediation^{TM} mix type and loading rate (Mix 2 at 10%), based on the results of the first round of bench-scale testing;
- Pilot treatment was conducted on much larger sample batches (15-20 gallons) instead of smaller batches (2,500 g) at the bench-scale level, in order to simulate the larger scale operation;
- The focus of the pilot treatment stage was to investigate the curing process with regard to the effect of curing period, adverse weather conditions (e.g. rain, humidity, cold, etc.) and space constraints (deeper curing piles) on the chemical effectiveness of the selected reagent mix;
- Geotechnical testing necessary to evaluate beneficial use potential of the treated material was conducted on the material treated at the pilot stage;

The detailed procedures and methods used for conducting pilot treatment and collecting treated samples for chemical analysis and geotechnical testing are provide in Section 5.8. The following abbreviations are being re-presented for the associated treatment and curing conditions used during pilot treatment of Stratus material using selected Georemediation^{TM} Mix 2, at 10% loading by wet weight of the material:

1. Slurried reagent addition (1:1 reagent to tap water ratio by weight), followed by curing at room temperature **(RT)**;
2. Slurried reagent addition (1:1 reagent to tap water ratio by weight), followed by curing at high relative humidity **(RH > 95%)**;
3. Slurried reagent addition (1:1 reagent to tap water ratio by weight), followed by curing at freezing temperatures (approximately 15° F) **[FR]**;
4. Slurried reagent addition (1:1 reagent to tap water ratio by weight), followed by curing in deeper curing pile (3 times deeper than the other piles, with relatively same surface area) **[DP]**;
5. Dry powder reagent addition (without tap water), followed by curing at room temperature **(DRY)**.

The following sections present the results of the pilot treatment. All data obtained for the samples treated during the pilot treatment stage was compared with the untreated re-characterization analysis data for the Stratus material, provided in Section 6.1.1.

6.1.4.1 *Effect of Curing Period and Adverse Weather Conditions*

The results of the samples treated and under the "RT", "RH > 95%", and "FR" conditions were compared with the untreated Stratus results to evaluate the effect of curing period, and adverse weather conditions, on the chemical effectiveness of the reagent mix. All treated samples were cured for a total period of 62 days, and treated samples were collected (in duplicate) at the end of 14-, 28-, and 62-day curing period. The detailed analytical results of the samples collected under these conditions (as summarized in Section 5.8.4) are provided in Appendix B-9.

Table 6-10 provides a comparison of the untreated and treated data for selected target contaminants based on their detection and/or exceedance above the applicable chemical decontamination success criteria (NJDEP RDCSCC, ATSDR guidance level, or NJDEP GWQS).

Table 6-10: Effect of Curing Period and Adverse Weather Conditions

Parameter	Curing Period (Days)	NJDEP RDCSCC (mg/kg)	Untreated Avg. (mg/kg)	Treated Concentration (mg/kg)			% Reduction		
				RT	RH >95 %	FR	RT	RH >95 %	FR
PAHs[a]				9.62					
Total PAHs	14	N/A	9.62	10.24	8.79	6.46	-6%	9%	33%
where did	28	N/A	9.62	4.28	6.19	8.20	56%	36%	15%
this come from	62	N/A	9.62	5.23	7.02	6.69	46%	27%	30%
				0.930					
Benzo(a)pyrene	14	0.66	0.93	1.10	0.90	0.66	-18%	3%	29%
	28	0.66	0.93	0.46	0.65	0.80	51%	30%	14%
	62	0.66	0.93	0.51	0.70	0.66	45%	25%	29%
				1.30					
Benzo(b)fluoranthene	14	0.90	1.30	1.30	1.10	0.77	0%	15%	41%
	28	0.90	1.30	0.55	0.85	1.10	58%	35%	15%
	62	0.90	1.30	0.59	0.77	0.72	55%	41%	45%
Metals[b]				14					
Arsenic	14	20	14	16.6	16.4	17.5	-19%	-17%	-25%
	28	20	14	16.0	15.5	16.4	-14%	-11%	-17%
	62	20	14	16.0	16.3	18.0	-14%	-16%	-29%
				137					
Lead	14	400	137	123	124	128	10%	9%	7%
	28	400	137	115	114	126	16%	17%	8%
	62	400	137	114	124	136	17%	9%	1%
Dioxins/Furans			(ppt)	212					
Total TEQ	14	50	212	94	85	55	55%	60%	74%
	28	50	212	316	174	142	-49%	18%	33%
	62	50	212	148	134	190	30%	37%	10%

main table!

[a] Total PAHs were calculated by adding the average concentration of seventeen (17) PAH compounds analyzed as part of the semi-volatiles (TCL-BNA+10) analysis

[b] Arsenic (As) and lead (Pb) are included in the above table since the MEP leachate results indicated exceedances above NJDEP GWQS for both metals

Table 6-11 presents Relative Percent Difference (RPD) values between the data collected under adverse weather conditions (“RH > 95%”, “FR”) and the data collected under room temperature and humidity conditions (“RT”). Shaded cells with RPD values greater than |±20%| represent a significant impact of the adverse weather conditions on the treatment results obtained under room temperature and humidity conditions (RT).

Table 6-11: Effect of Adverse Weather Conditions (Relative Percent Difference)

Parameter	Curing Period (Days)	Treated Concentration (mg/kg)			Relative Percent Difference (RPD)[b]	
		RT	RH >95%	FR	RPD$_{RT-RH}$	RPD$_{RT-FR}$
PAHs[a]						
Total PAHs	14	10.24	8.79	6.46	15%	45%
	28	4.28	6.19	8.20	-36%	-63%
	62	5.23	7.02	6.69	-29%	-24%
Benzo(a)pyrene	14	1.10	0.90	0.66	20%	50%
	28	0.46	0.65	0.80	-34%	-54%
	62	0.51	0.70	0.66	-31%	-26%
Benzo(b)fluoranthene	14	1.30	1.10	0.77	17%	51%
	28	0.55	0.85	1.10	-43%	-67%
	62	0.59	0.77	0.72	-26%	-20%
Metals						
Arsenic	14	16.6	16.4	17.5	1%	-5%
	28	16.0	15.5	16.4	3%	-2%
	62	16.0	16.3	18.0	-2%	-12%
Lead	14	123	124	128	-1%	-4%
	28	115	114	126	1%	-9%
	62	114	124	136	-8%	-18%
Dioxins/Furans			ppt			
Total TEQ	14	94	85	55	10%	52%
	28	316	174	142	58%	76%
	62	148	134	190	10%	-25%

[a] Total PAHs were calculated by adding the average concentration of seventeen (17) PAH compounds analyzed as part of the semi-volatiles (TCL-BNA+10) analysis

[b] Relative Percent Difference (RPD) calculated for both “RH” and “FR” conditions with respect to “RT” values (e.g. RPD$_{RT-RH}$: (“RT” Value – “FR” Value)/Average Value) x 100%). Shaded cells indicate statistically significant difference due to RPD values > |±20%|

A graphical comparison of the results presented in Table 6-10 is presented in Figures 6-1, 6-2, 6-3, 6-4, and 6-5.

Figure 6-1: Effect of Curing Period and Adverse Weather Conditions on the Georemediation^{TM} Treatment Results (Total PAHs)

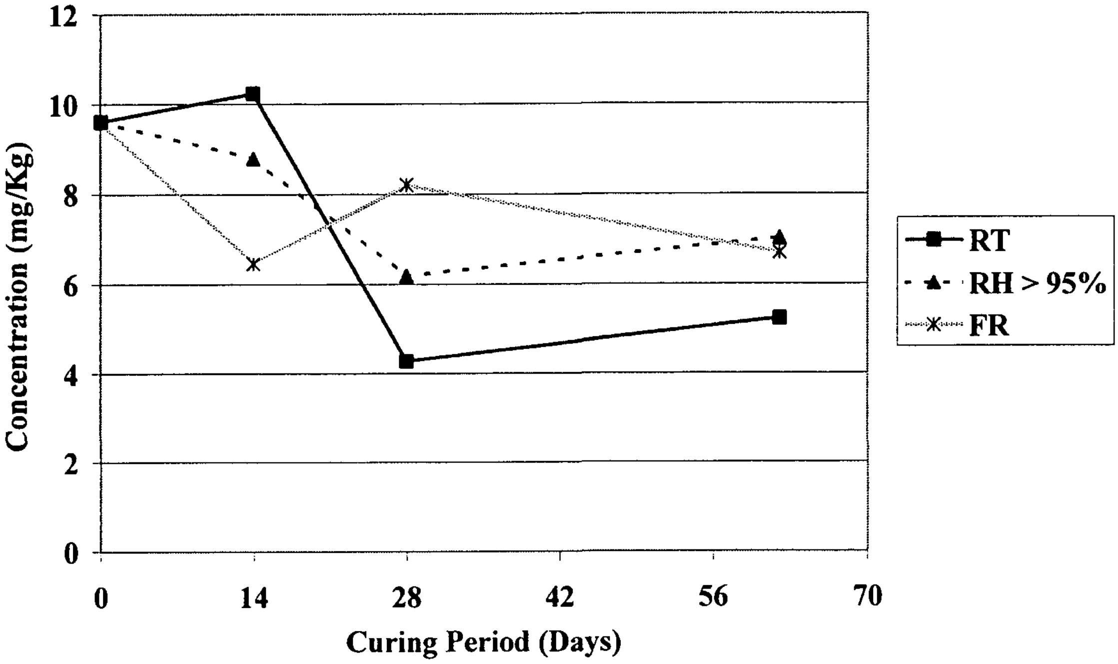


Figure 6-2: Effect of Curing Period and Adverse Weather Conditions on the Georemediation^{TM} Treatment Results [Benzo(a)pyrene]

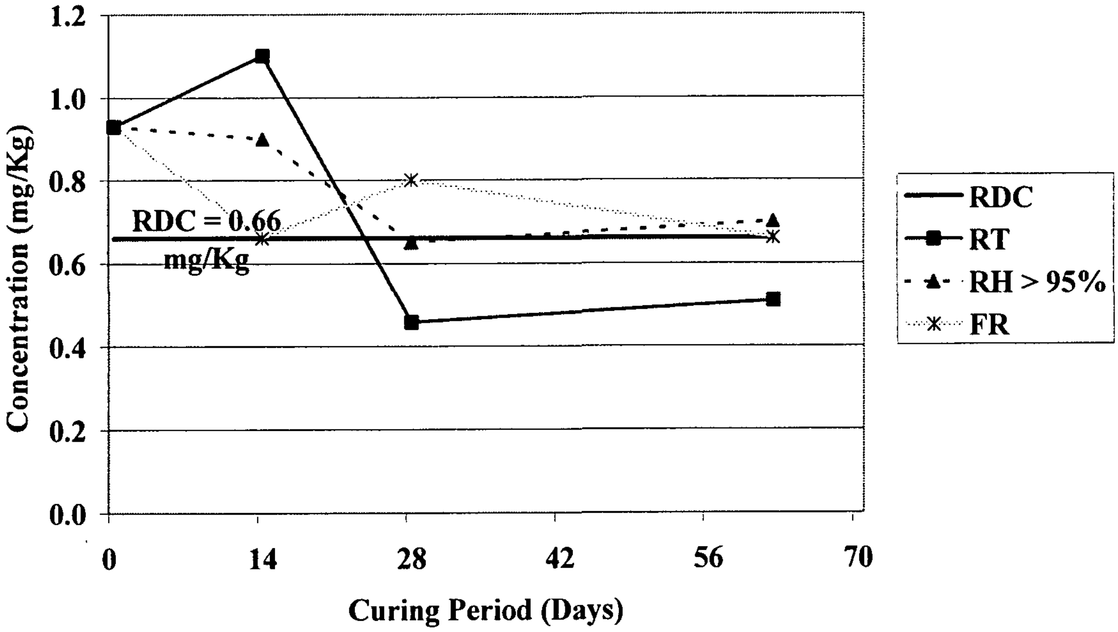


Figure 6-3: Effect of Curing Period and Adverse Weather Conditions on the Georemediation^{TM} Treatment Results [Benzo(b)fluorantene]

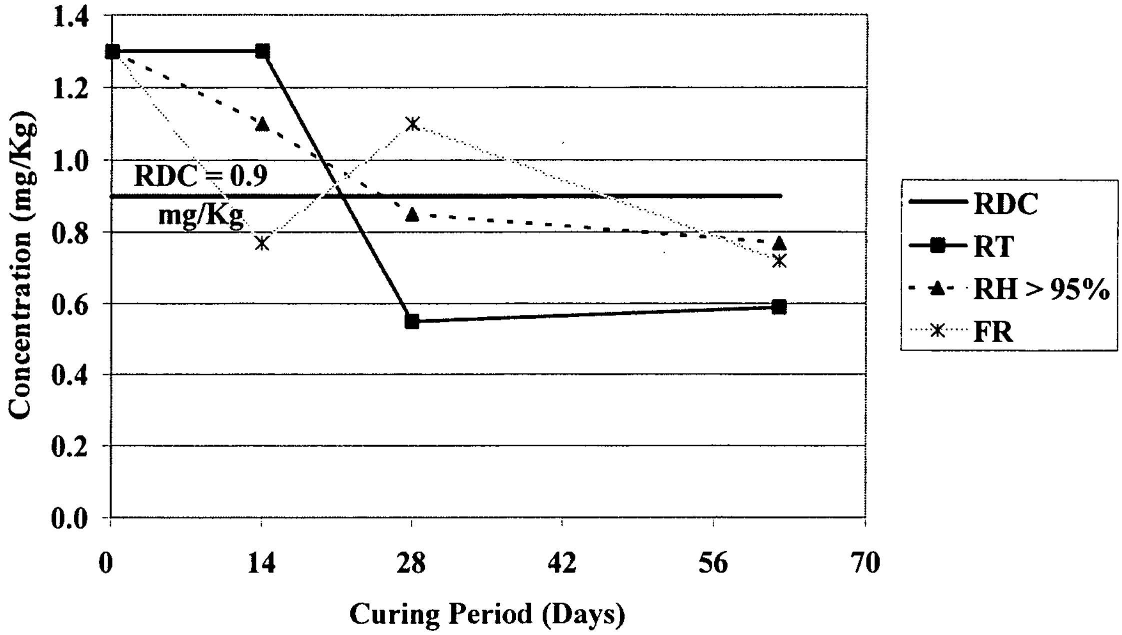


Figure 6-4: Effect of Curing Period and Adverse Weather Conditions on the Georemediation^{TM} Treatment Results [Arsenic]

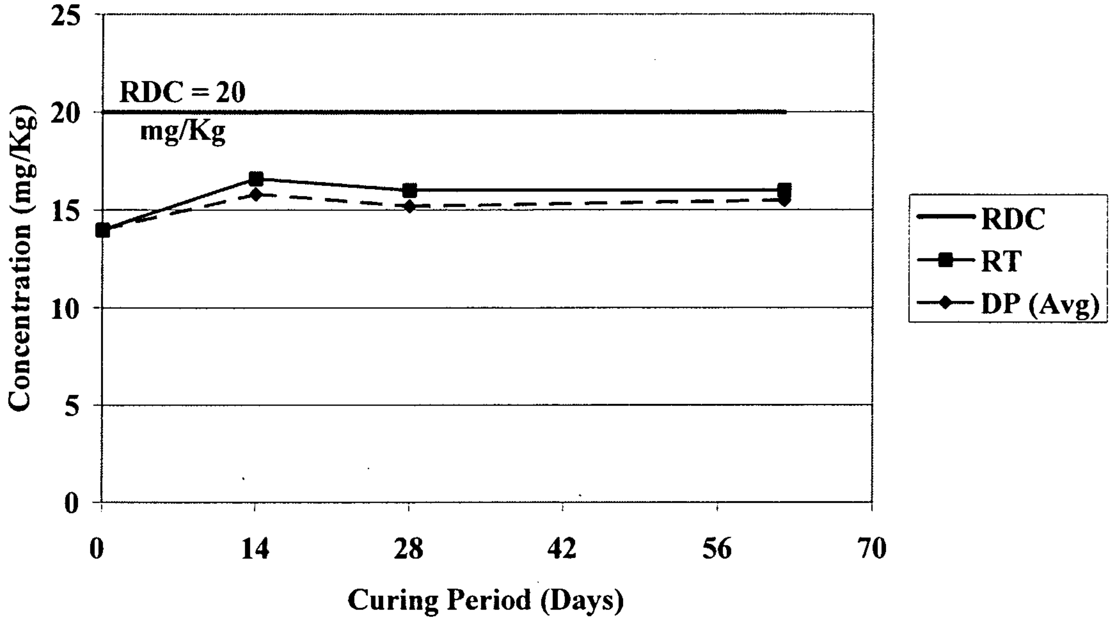
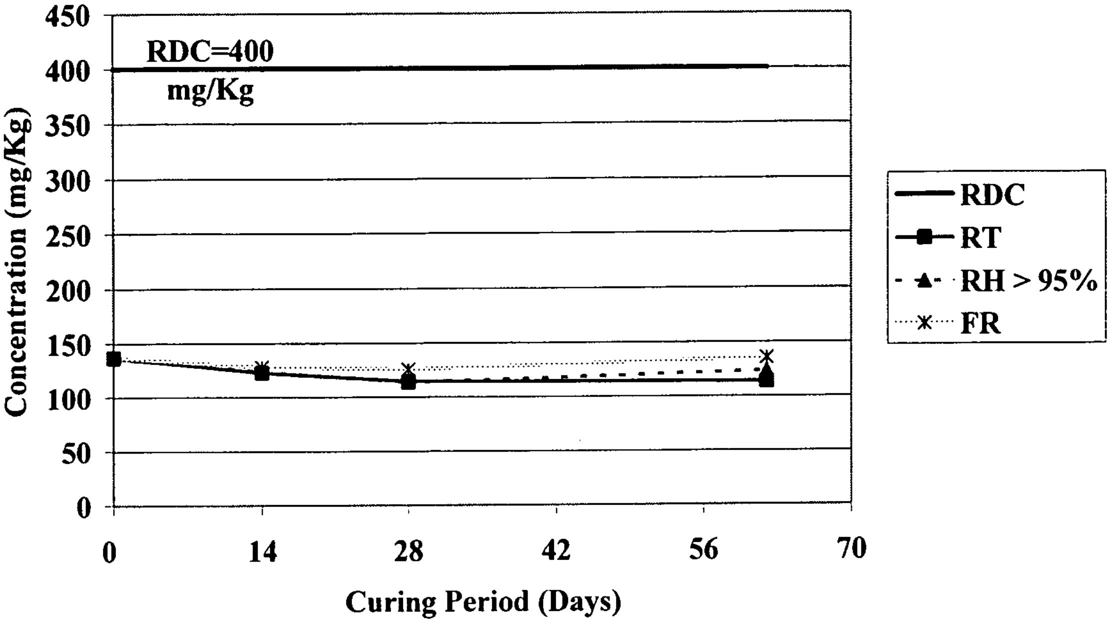


Figure 6-5: Effect of Curing Period and Adverse Weather Conditions on the Georemediation™ Treatment Results [Lead]



The figures presented above demonstrate the effect of curing period and the adverse weather conditions on the chemical effectiveness of the Georemediation™ Mix 2 (10% loading) on organic (PAHs) and metal (arsenic and lead) contaminants. Other organic contaminants (TPHCs, Pesticides, PCBs, etc.) were not included in this analysis, since they were either not detected or were present at very low levels in the untreated Stratus material. As later presented, arsenic (As) and lead (Pb) were the only two target heavy metals with exceedances above the NJDEP GWQS during the MEP leaching test. Dioxins/Furans testing was also performed for the above treatment and curing conditions. However, the results obtained were largely inconclusive due to difficulties encountered by the analytical laboratory in analyzing the dioxins, thereby severely jeopardizing the credibility of the data. The analytical issues related to the dioxins/furans analysis are presented in detail in Section 6.3.

The following provides a summary of the observations based on the PAHs results:

- A significant reduction in PAH compounds is obtained after the 28-day curing period as compared to 14-day curing period;
- No significant improvement in PAHs reduction is noted between 28-day and 62-day curing data;
- Material cured at room temperature conditions (RT) showed the highest effectiveness in reducing PAHs contamination, as compared to material cured at high humidity (RH > 95%) or freezing conditions (FR);
- Although, more data is required, both high relative humidity (RH > 95%) and freezing condition (FR) appear to have negative impact on the reduction of organic contaminants (PAHs, dioxins). However, freezing conditions (FR) seem to more severely limit the decontamination of the organics;

- Material cured at room temperature conditions (RT) was generally able to achieve the reduction of PAH contaminants below the NJDEP RDCSCC after the 28-day curing period;

The following provides a summary of the observations based on the metals (arsenic and lead) results:

- No significant reduction in total metals concentration was observed in any of the treatment and curing conditions;
- A general increase in the total arsenic (As) concentration was observed for all treatment and curing conditions;
- The total concentration of none of the target heavy metals exceeded the NJDEP RDCSCC before or after the treatment and curing conditions.

6.1.4.2 Effect of Dry Georemediation^{TM} Reagent Addition

In past studies and applications, Georemediation^{TM} treatment has generally consisted of mixing of the reagent with an equal or higher amount (by weight) of water to make a slurry, which is then mixed with the contaminated media. Sufficient moisture is required during the treatment process to catalyze some of the oxidation and hydrolysis reactions necessary for the decontamination of the material. However, the ability to add the Georemediation^{TM} reagent to the contaminated media in the dry form, without jeopardizing the chemical effectiveness of the treatment may result in significant savings in operational cost necessary for the slurrying of the reagent.

Dredged material generally has high moisture content (45% to 65%) as compared to contaminated soils (<20%). Although, the Georemediation^{TM} treatment process uses the inherent moisture of the contaminated media to benefit the decontamination mechanisms, it is not clear, if the pre-slurrying of the reagent is more effective than the addition of dry reagent in a wet media such as dredged material. Therefore, as part of this pilot study, one batch of pilot treatment was conducted on the Stratus material (approximate moisture content of 58%) using dry powder addition of the Georemediation^{TM} Mix 2.

Table 6-12 presents a comparison of analytical data for target parameters for Stratus material treated using a slurried Georemediation™ reagent and cured at room temperature (RT), and Stratus material treated using a dry Georemediation™ reagent and cured at room temperature (DRY). The detailed analytical results of the samples collected under the "DRY" condition are provided in Appendix B-10.

Table 6-12: Effect of Dry Georemediation™ Reagent Addition

Parameter	Curing Period (Days)	NJDEP RDCSCC (mg/kg)	Untreated Avg. (mg/kg)	Treated Concentration (mg/kg)		% Reduction		RPD_{RT-DRY}[c]
				RT	DRY	RT	DRY	
PAHs[a]								
Total PAHs	14	N/A	9.62	10.24	8.23	-6%	14%	22%
	28	N/A	9.62	4.28	7.29	56%	24%	-52%
	62	N/A	9.62	5.23	8.23	46%	14%	-45%
Benzo(a)pyrene	14	0.66	0.93	1.10	0.91	-18%	2%	19%
	28	0.66	0.93	0.46	0.74	51%	20%	-47%
	62	0.66	0.93	0.51	0.83	45%	11%	-48%
Benzo(b)fluoranthene	14	0.90	1.30	1.30	1.10	0%	15%	17%
	28	0.90	1.30	0.55	1.00	58%	23%	-58%
	62	0.90	1.30	0.59	0.89	55%	32%	-41%
Metals[b]								
Arsenic	14	20	14	16.6	16.5	-19%	-18%	1%
	28	20	14	16.0	16.7	-14%	-19%	-4%
	62	20	14	16.0	16.6	-14%	-19%	-4%
Lead	14	400	137	123	123	10%	10%	0%
	28	400	137	115	117	16%	15%	-2%
	62	400	137	114	119	17%	13%	-4%
Dioxins/Furans			(ppt)					
Total TEQ	14	50	212	94	162	55%	24%	-53%
	28	50	212	316	150	-49%	29%	71%
	62	50	212	148	160	30%	25%	-8%

[a] Total PAHs were calculated by adding the average concentration of seventeen (17) PAH compounds analyzed as part of the semi-volatiles (TCL-BNA+10) analysis

[b] Arsenic (As) and lead (Pb) are included in the above table since the MEP leachate results indicated exceedances above NJDEP GWQS for both metals

[c] Relative Percent Difference (RPD) calculated for "DRY" condition with respect to "RT" values (e.g. RPD_{RT-DRY}: ("RT" Value – "DRY" Value)/Average Value) x 100%). Shaded cells indicate statistically significant difference due to RPD values > |±20%|

Table 6-12 also presents Relative Percent Difference (RPD) values between the data collected under dry reagent addition conditions ("DRY") and the data collected under room temperature and humidity conditions ("RT"). Shaded cells with RPD values greater than |±20%| represent a significant impact of the use of dry reagent on the treatment results obtained using slurried reagent conditions (RT).

A graphical comparison of the PAHs results for the material treated and cured under the "RT" and "DRY" conditions is presented in Figures 6-6, 6-7, and 6-8.

Figure 6-6: Effect of Dry Georemediation™ Reagent Addition on the Treatment Results [Total PAHs]

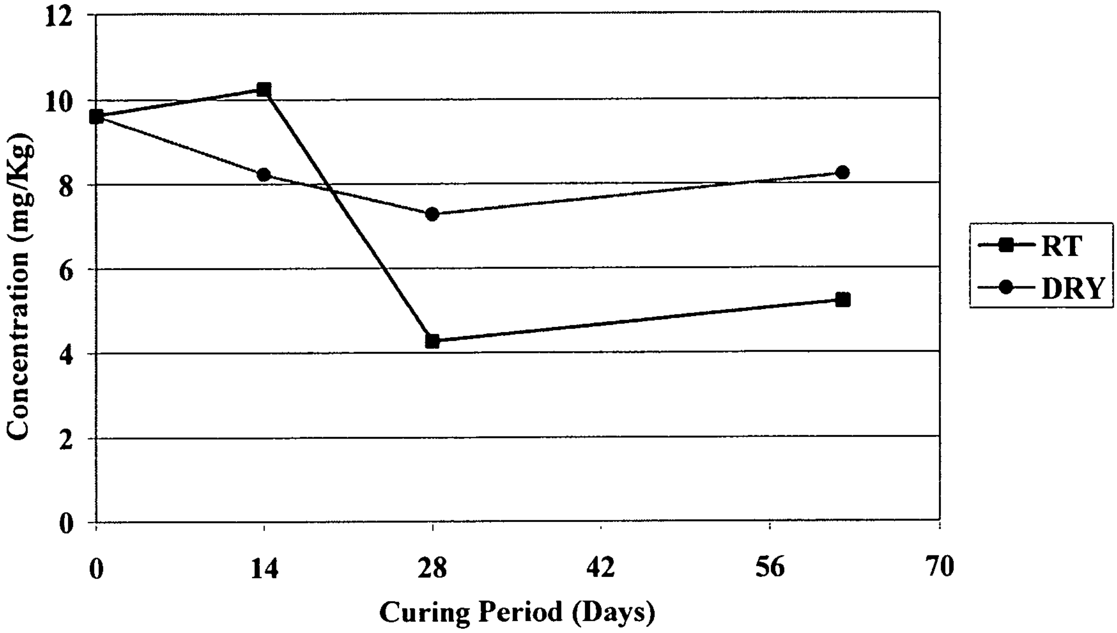


Figure 6-7: Effect of Dry Georemediation™ Reagent Addition on the Treatment Results [Benzo(a)pyrene]

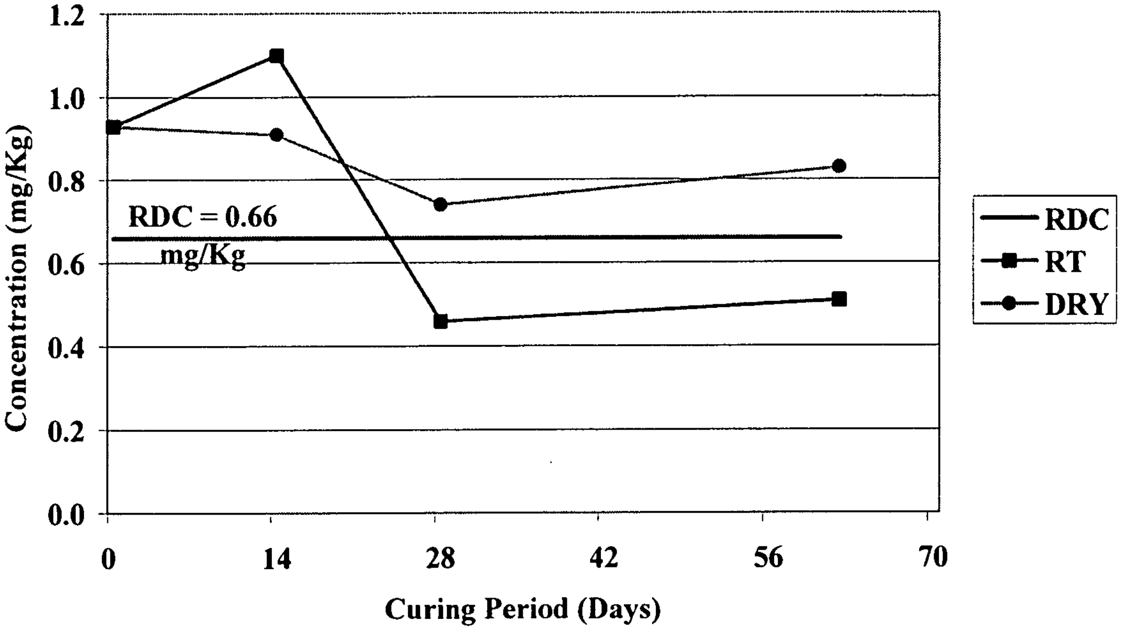
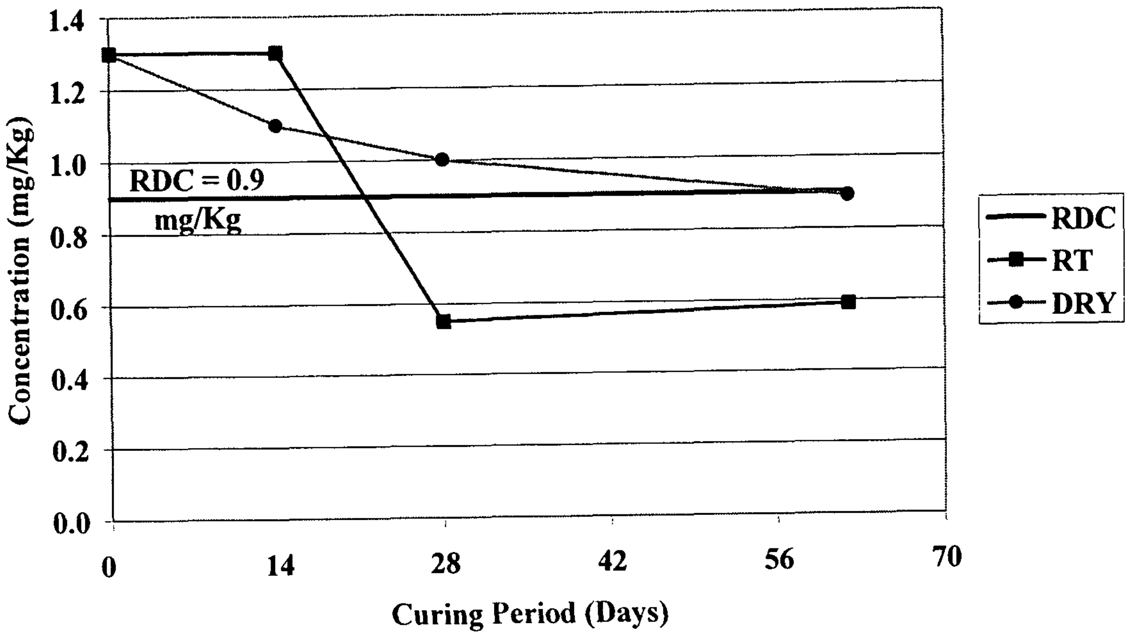


Figure 6-8: Effect of Dry Georemediation^{TM} Reagent Addition on the Treatment Results [Benzo(b)fluoranthene]



Graphical comparison for the metals data is not presented, as similar conclusions were derived as previously presented for material cured under adverse weather conditions "RH > 95%" and "FR". However, the following observations were made for the results of the PAHs analysis:

- Although, higher percent reduction in PAH compounds was observed at 28-day curing period as compared to 14-day curing period, material treated with dry Georemediation^{TM} reagent showed significantly less reduction in PAHs than material treated with slurried reagent;
- In general, a negative impact of the effect of dry reagent was observed in the reduction of PAHs compounds as compared to the treatment using slurried reagent (RT);
- Georemediation^{TM} treatment of Stratus material using dry reagent was unsuccessful in reducing the target PAH contaminants below the NJDEP RDCSCC based on the 62-day curing period.

Dioxins/Furans testing was also performed for the above treatment and curing conditions. However, the results obtained were largely inconclusive due to difficulties encountered by the analytical laboratory in analyzing the dioxins, thereby severely jeopardizing the credibility of the data. The analytical issues related to the dioxins/furans analysis are presented in detail in Section 6.3.

6.1.4.3 Effect of Deeper Curing Piles

Although, the pilot study was conducted in a closed laboratory setting with limited material and space constraints, an attempt was made to evaluate the effect of increased depth of curing piles on the chemical effectiveness of the Georemediation^{TM} process. Since the application of Georemediation^{TM} technology involves on-site curing of the material for several weeks, more shallow curing piles will require larger plot area, thereby increasing the treatment facility and operational costs of the Georemediation™ process.

For this purpose, Stratus material was treated and cured at room temperature under the "DP" conditions, with the curing pan three (3) times deeper (1.5' deep) than the material treated at room temperature under "RT" conditions (0.5' deep). Duplicate samples were collected from three (3) depth zones of the deeper curing pile at various curing periods, following the procedures detailed in Section 5.8.4. For a comparison of "DP" data with "RT" data, an average data for six (6) samples collected across three (3) depth zones was used for each curing period.

Table 6-13 presents a comparison of analytical data for target parameters for Stratus material treated using a slurried Georemediation™ reagent and cured at room temperature (RT), and Stratus material treated using a slurried Georemediation™ reagent and cured at room temperature in deeper curing pile (DP). The detailed analytical results of the samples collected under the "DP" condition are provided in Appendix B-11.

Table 6-13: Effect of Deeper Curing Pile

Parameter	Curing Period (Days)	NJDEP RDCSCC (mg/kg)	Untreated Avg. (mg/kg)	Treated Concentration (mg/kg)		% Reduction		RPD$_{RT-DPAvg}$[c]
				RT	DP (Avg.)	RT	DP (Avg.)	
PAHs[a]								
Total PAHs	14	N/A	9.62	10.24	8.75	-6%	9%	16%
	28	N/A	9.62	4.28	5.59	56%	42%	-27%
	62	N/A	9.62	5.23	4.25	46%	56%	21%
Benzo(a)pyrene	14	0.66	0.93	1.10	0.94	-18%	-1%	16%
	28	0.66	0.93	0.46	0.59	51%	37%	-25%
	62	0.66	0.93	0.51	0.42	45%	55%	19%
Benzo(b)fluoranthene	14	0.90	1.30	1.30	1.20	0%	8%	8%
	28	0.90	1.30	0.55	0.75	58%	42%	-31%
	62	0.90	1.30	0.59	0.45	55%	65%	27%
Metals[b]								
Arsenic	14	20	14	16.6	15.8	-19%	-13%	5%
	28	20	14	16.0	15.2	-14%	-9%	5%
	62	20	14	16.0	15.5	-14%	-11%	3%
Lead	14	400	137	123	125	10%	9%	-2%
	28	400	137	115	116	16%	15%	-1%
	62	400	137	114	121	17%	12%	-6%
Dioxins/Furans			(ppt)					
Total TEQ	14	50	212	94	175	55%	18%	-60%
	28	50	212	316	156	-49%	27%	68%
	62	50	212	148	155	30%	27%	-5%

[a] Total PAHs were calculated by adding the average concentration of seventeen (17) PAH compounds analyzed as part of the semi-volatiles (TCL-BNA+10) analysis

[b] Arsenic (As) and lead (Pb) are included in the above table since the MEP leachate results indicated exceedances above NJDEP GWQS for both metals

[c] Relative Percent Difference (RPD) calculated for "DPAvg" condition with respect to "RT" values (e.g. $RPD_{RT\text{-}DRY}$: ("RT" Value – "DRY" Value)/Average Value) x 100%). Shaded cells indicate statistically significant difference due to RPD values > |±20%|

Table 6-13 also presents Relative Percent Difference (RPD) values between the data collected under the deeper curing pile conditions ("DP Avg") and the data collected under shallower pile cured at room temperature and humidity conditions ("RT"). Shaded cells with RPD values greater than |±20%| represent a significant impact of the deeper curing pile on the treatment results obtained under shallower curing pile conditions (RT).

A graphical comparison of the PAHs results for the material treated under "RT" and "DP" conditions is presented in Figures 6-9, 6-10, and 6-11.

Figure 6-9: Effect of Deeper Curing Pile on the Treatment Results [Total PAHs]

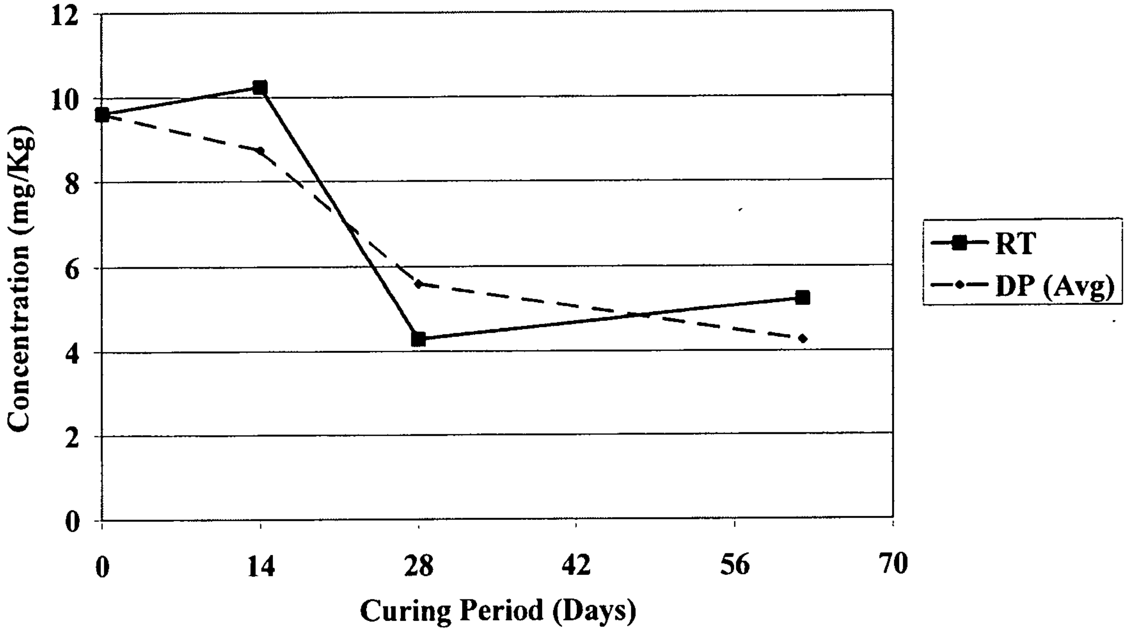


Figure 6-10: Effect of Deeper Curing Pile on the Treatment Results [Benzo(a)pyrene]

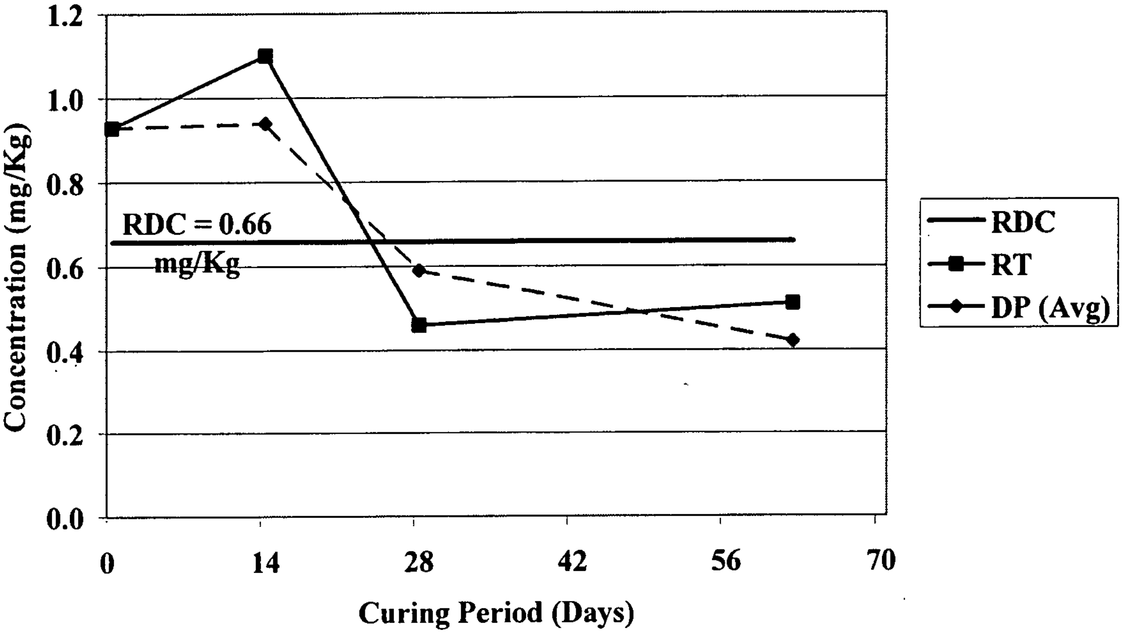
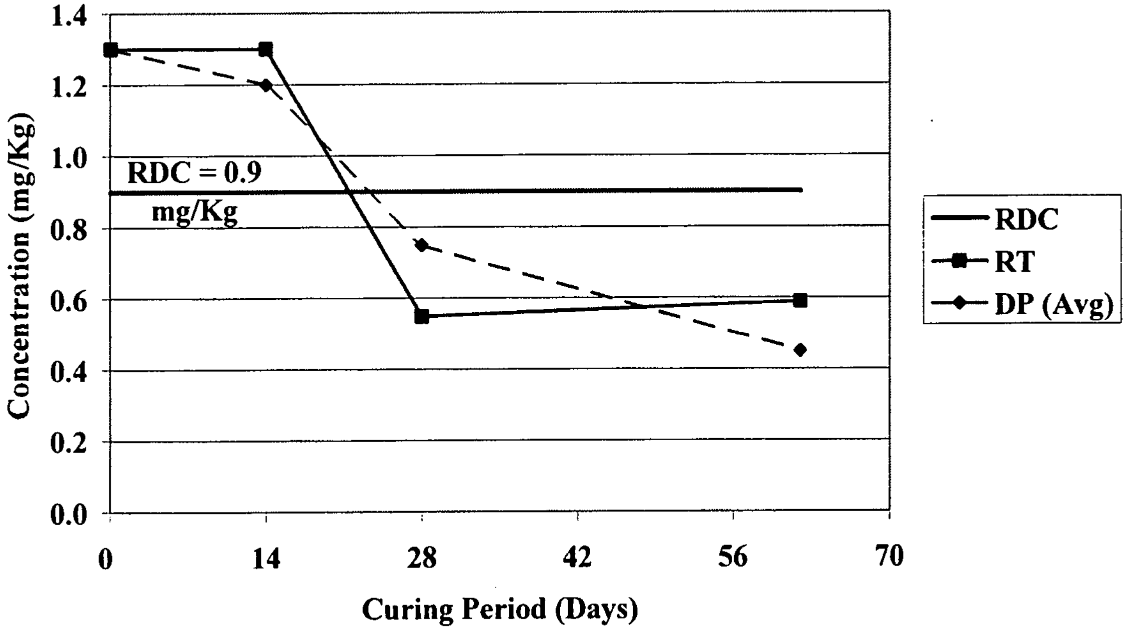


Figure 6-11: Effect of Deeper Curing Pile on the Treatment Results [Benzo(b)fluoranthene]



Graphical comparison for the metals data is not presented, as similar conclusions were derived as previously presented for material cured under adverse weather conditions "RH > 95%" and "FR". However, the following observations were made for the results of the PAHs analysis:

- In general, a positive impact of the effect of deeper curing piles was observed on the reduction of PAHs compounds as compared to material cured under "RT" conditions;
- In addition, PAHs contamination in the deeper curing pile (DP) was reduced below the NJDEP RDCSCC for applicable compounds after the 28-day curing period.

6.1.4.4 Effect of Curing Pile Depth on PAHs Results

In addition to comparing the average "DP" data with the "RT" data, the analytical results from the three individual depth zones of the deeper curing pile were also compared. The purpose of this analysis was to determine the difference in the effectiveness of the Georemediation^{TM} treatment of the surficial and the deeper material. The results of this analysis may dictate the need for constant tilling of the treated material during the curing process at the full-scale level. Since the results of the metals analysis were quite similar, and dioxin results were largely inconclusive, a comparison of only the target PAHs for the three depth zones was conducted and is presented in Table 6-14.

Table 6-14: Effect of Depth on PAHs Results

Parameter	**Curing Period (Days)**	**NJDEP RDCSCC (mg/kg)**	**Untreated Avg. (mg/kg)**	**Treated Concentration by Depth (mg/kg)**			**% Reduction by Depth**		
				A (0-6")	**B (6-12")**	**C (12-18")**	**A (0-6")**	**B (6-12")**	**C (12-18")**
PAHs[a]									
Total PAHs	14	N/A	9.62	9.94	7.75	8.76	-3%	19%	9%
	28	N/A	9.62	6.20	5.82	4.83	36%	40%	50%
	62	N/A	9.62	4.73	3.70	4.33	51%	62%	55%
Benzo(a)pyrene	14	0.66	0.93	1.10	0.83	0.94	-18%	11%	-1%
	28	0.66	0.93	0.65	0.62	0.52	30%	33%	44%
	62	0.66	0.93	0.46	0.36	0.45	51%	61%	52%
Benzo(b)fluoranthene	14	0.90	1.30	1.40	1.00	1.20	-8%	23%	8%
	28	0.90	1.30	0.83	0.78	0.65	36%	31%	50%
	62	0.90	1.30	0.51	0.39	0.46	61%	70%	65%

A graphical comparison of the PAHs results for the material for the three (3) depth zones under the "DP" conditions is presented in Figures 6-12, 6-13, and 6-14.

Figure 6-12: Effect of Depth on the Treatment Results [Total PAHs]

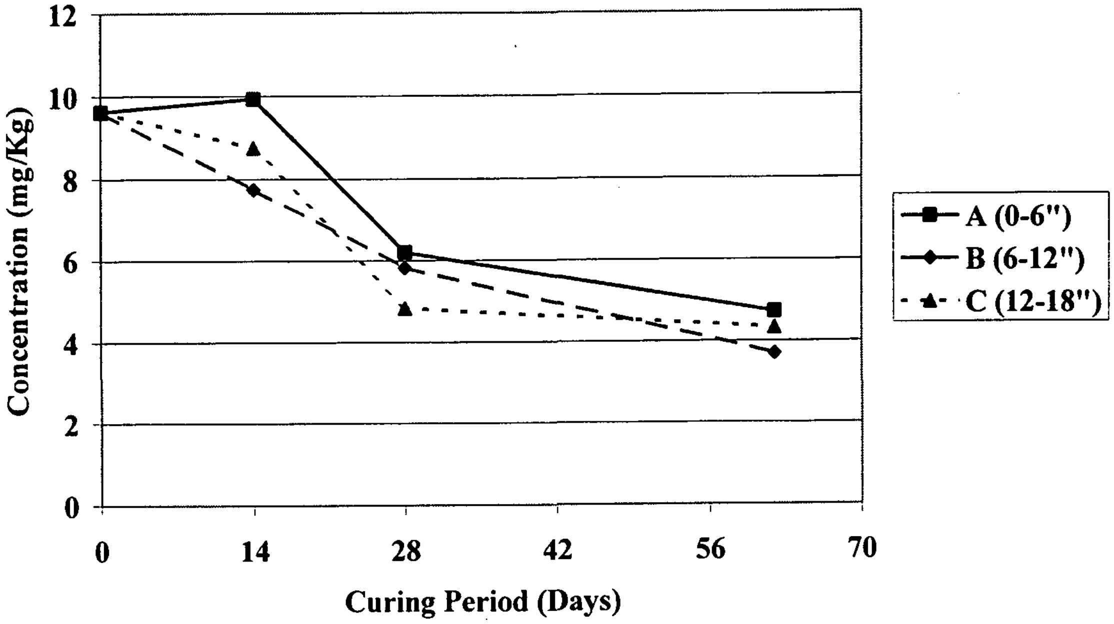


Figure 6-13: Effect of Depth on the Treatment Results [Benzo(a)pyrene]

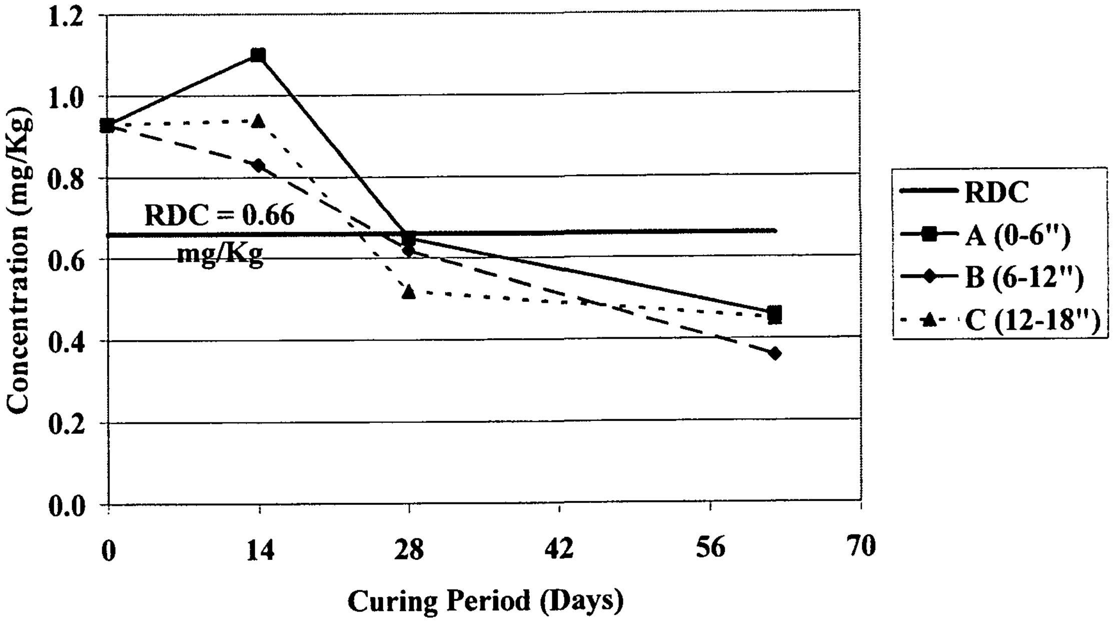
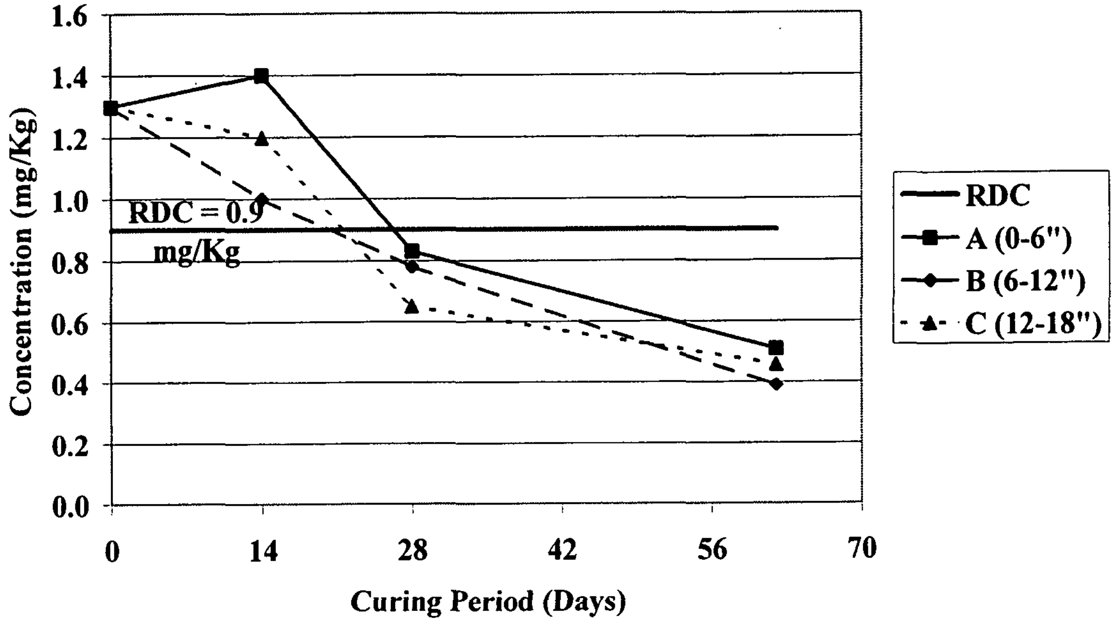


Figure 6-14: Effect of Depth on the Treatment Results [Benzo(b)fluoranthene]



The following observations were made for the results of the PAHs analysis for the three (3) depth zones of the deeper curing pile:

- Although, no significant difference is observed in the PAHs reduction among three (3) different depths of the deeper curing pile, the confined material (Depth "B": 6-12") appears to show consistently higher PAHs reductions than the surficial material (Depth "A": 0-6") and the bottom material (Depth "C": 12-18");
- The reduction in PAHs has consistently improved over the curing period, as previously observed in other treatment and curing conditions. For the samples collected from Depth "B" (6-12"), a consistent improvement in PAHs reduction is noted after 62-day curing period, as compared to 28-day curing period (60-70% reduction). This may suggest that although the decontamination of the organics may continue for longer periods after the treatment.

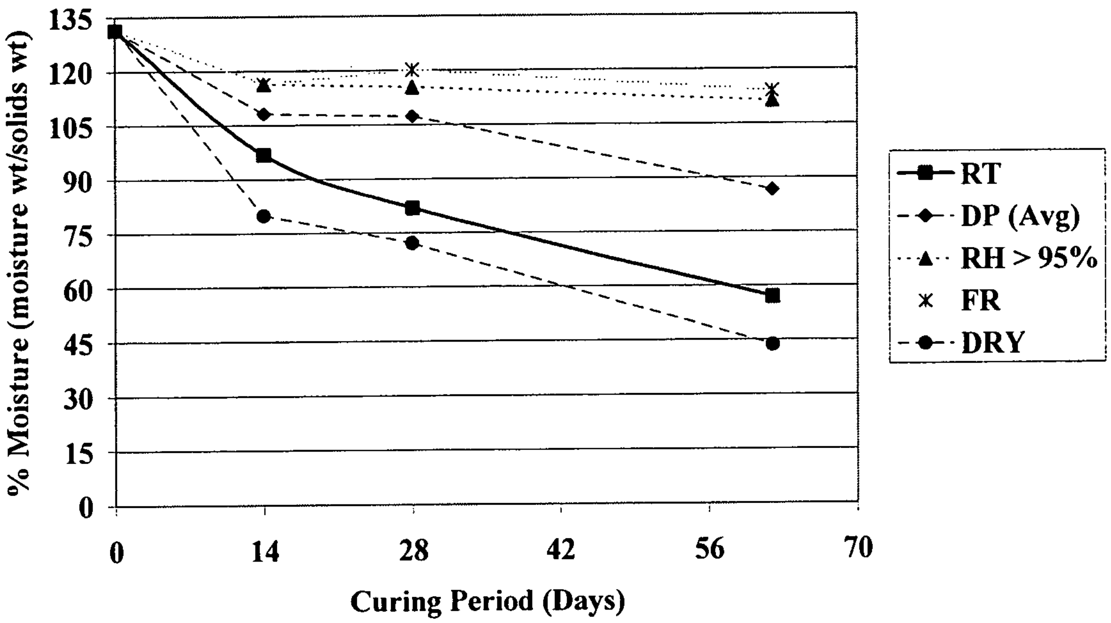
Although, the above observations are based on limited data due to lack of the presence of other contaminants (e.g. Pesticides, PCBs, etc.) in the Stratus material, the results may have significant implications on the handling of the material during the curing process. The results seem to indicate that material in the confined layer shows higher organic decontamination. Therefore, deeper curing piles may be advantageous for organic decontamination due to increased bulking and confinement of the treated material. In addition, tilling of the material during curing process may reduce the chemical effectiveness of the Georemediation^{TM} process. Although, these observations will need to be corroborated for a wider range of organic contaminants at larger scale testing, the results will impact the economics of the Georemediation^{TM} treatment operations at the demonstration and full-scale levels.

6.1.4.5 *Effect of Curing Period on Moisture Content*

Moisture content of the Stratus material treated and cured with Georemediation™ Mix 2 at 10% loading at the pilot stage under all five (5) conditions was measured. The moisture content was calculated as the weight of the moisture (water) in the material per unit weight of the dry solids in the sediments, and expressed as a percentage (%). The results are based on the curing of material inside the closed laboratory, either at room temperature or under simulated adverse weather conditions, and without direct exposure to sunlight. In addition, the moisture data presented in this section is based on the analytical samples collected and submitted to the analytical laboratory, and are not based on standard ASTM method D 2216, used by BEM to determine moisture content in the laboratory.

Figure 6-15 provides a comparison of the moisture content (%) for all five (5) treatment and curing conditions for the Stratus material.

Figure 6-15: Effect of Curing Period on Moisture Content



The following observations can be made from the comparison of the moisture content over curing period for samples treated and cured under various conditions:

- As anticipated, material cured under high relative humidity (RH > 95%) and freezing conditions (FR) shows limited reduction in the moisture content;
- Material treated using slurried and dry reagent and cured under room temperature conditions (RT and DRY) shows steady reduction in moisture content throughout the curing process;
- Curing of the material in deeper pile (DP) significantly limits the reduction in the moisture content of the material as compared to the more shallow pile (RT). Therefore, material cured in deeper pile will require longer to achieve required moisture content for field compaction of the material.

As later detailed in Geotechnical Testing results presented in Section 6.2, the target moisture content for the material treated using Georemediation™ Mix 2 at 10% loading (RT) is 36-39%. For treated samples cured for geotechnical testing, the target moisture content was achieved in approximately 34-43 days. Figure 6-15 indicates generally higher moisture content than the target value throughout the curing period (up to 62-days). However, less time is anticipated for material cured in open, and exposed to direct sunlight and wind. BEM's target curing time period is considered to be approximately four (4) weeks (28 days), and is likely achievable in field conditions based on the laboratory results of this study.

6.1.4.6 Effect of Georemediation™ Treatment on Contaminant Leaching

The results of the MEP leaching test on the untreated Stratus material were previously presented in Section 6.1.1. The results indicated exceedances of certain pesticides and metals (arsenic and lead) above the NJDEP GWQS, for one or more of the seven (7) extraction steps.

The Stratus material treated during pilot stage using slurried Georemediation™ Mix 2 (10% loading) and cured at room temperature (RT) was also tested for contaminant leaching using MEP leaching test at the end of a 28-day curing period. The samples were analyzed after the 28-day curing period, which is likely to be representative of the curing period at full-scale conditions prior to the beneficial use of the treated material.

Table 6-15 presents the MEP results for the treated Stratus material for the same selected parameters that exceeded the NJDEP GWQS for the untreated Stratus material.

Table 6-15: Treated Stratus Material MEP Leaching Test Results (Mix 2)

Parameter	NJDEP GWQS (µg/l)	Treated MEP Results (µg/l)[a]						
		L1	L2	L3	L4	L5	L6	L7
SVOCs								
(No Exceedances) ?	N/A							
Pesticides/PCBs								
alpha BHC	0.02	0.79	0.97	1.50	1.50	0.76	0.53	1.60
gamma BHC (Lindane)	0.2	0.37	0.39	0.68	0.56	0.28	0.14	0.84
Dieldrin	0.03	0.062	0.078	0.11	0.16	0.19	0.096	0.21
Dioxins/Furans								
(No Exceedances) *[L1 & L7 only]* ?	N/A	?						?
Metals (heavy)								
Arsenic	8	3.50	2.80	4.40	8.10	11.60	15.30	13.30
Lead	10	1.40	0.55	0.55	0.55	3.80	5.40	19.50

[a] Shaded cells indicate exceedances above the NJDEP GWQS

N/A – Not Applicable

The MEP results of the treated material indicate slight increase in the leaching of the pesticide compounds. However, no pesticides (except Dieldrin) were detected during the untreated Stratus material characterization at the method detection limits specified by NJDEP.

The MEP leaching results of the treated material still show metal exceedances above the NJDEP GWQS. However, the leaching of the metals appears to have been reduced. The MEP results for both arsenic (As) and lead (Pb) for the untreated and treated Stratus material are compared in Figures 6-16 and 6-17, respectively.

Figure 6-16: MEP Leachate Results for Untreated and Treated Stratus Material [Arsenic] – Mix 2

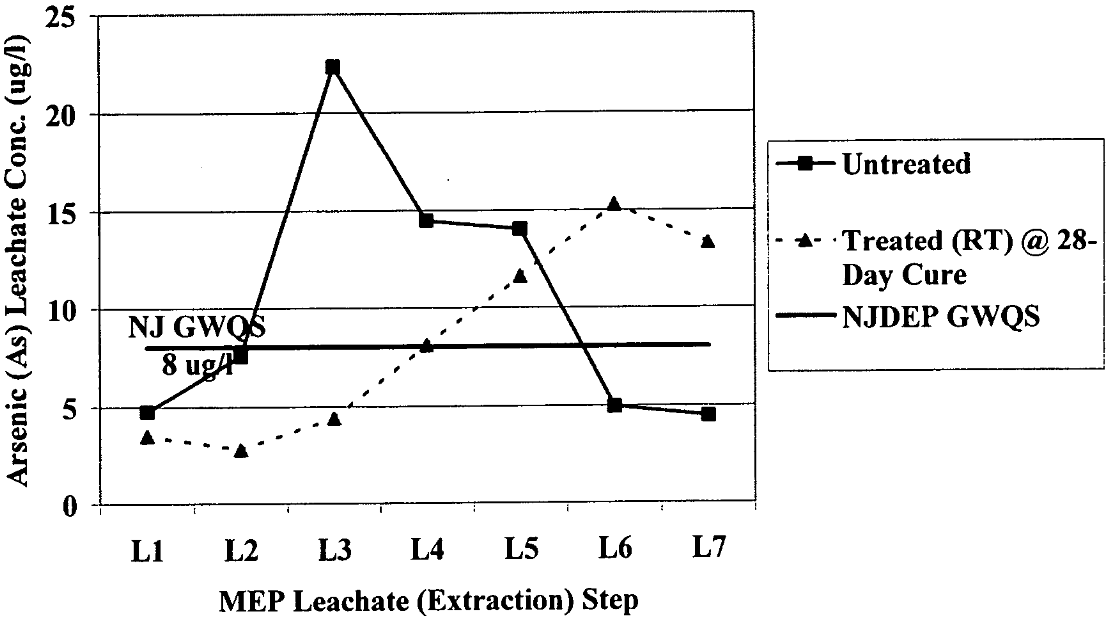
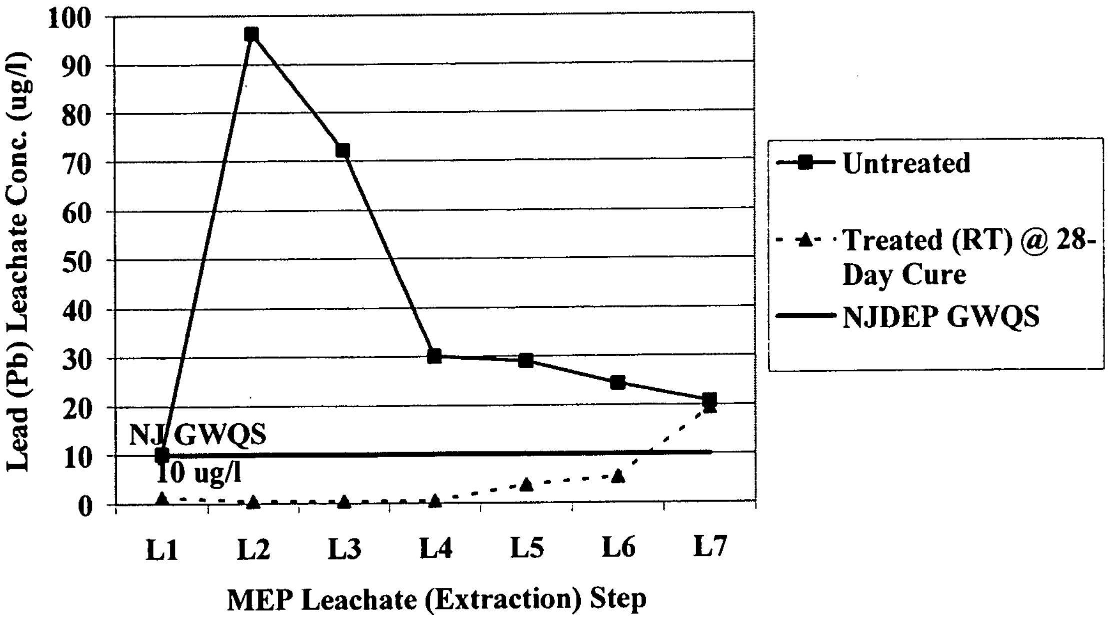


Figure 6-17: MEP Leachate Results for Untreated and Treated Stratus Material [Lead] – Mix 2



The following observations were made from the MEP leachate results for metals:

- In general, the treated material shows a reduction in the metals concentration in the leachate during the initial the MEP extractions steps. However, a gradual increase in the metal concentrations is observed for the treated material over the MEP extraction steps;
- The treated material shows a better stabilization of lead (Pb) contamination as compared to arsenic (As);
- Both arsenic (As) and lead (Pb) exceeded the NJDEP GWQS during one or more extraction steps of the MEP test.

Two new Georemediation^{TM} mixes (Mix 4 and Mix 5) were designed at tested as part of the second round of bench-scale treatment on the Stratus material to address the leaching of metals above the NJDEP GWQS, as detailed in Section 5.7.4. In addition to the total metals and dioxins/furans analysis, the treated samples were subjected to the MEP leaching test, with the leachate analyzed only for arsenic (As) and lead (Pb) at each extraction step. The total and MEP leachate results of this bench-scale treatment are were previously presented in Section 6.1.2.4.

Figures 6-18 and 6-19 provide a graphical comparison of the MEP leaching results for arsenic (As) and lead (Pb) for the untreated and Georemediation^{TM} (Mix 4 and Mix 5) treated Stratus material after the second round of bench-scale treatment.

Figure 6-18: MEP Leachate Results for Untreated and Treated Stratus Material [Arsenic] – Mix 4 and Mix 5

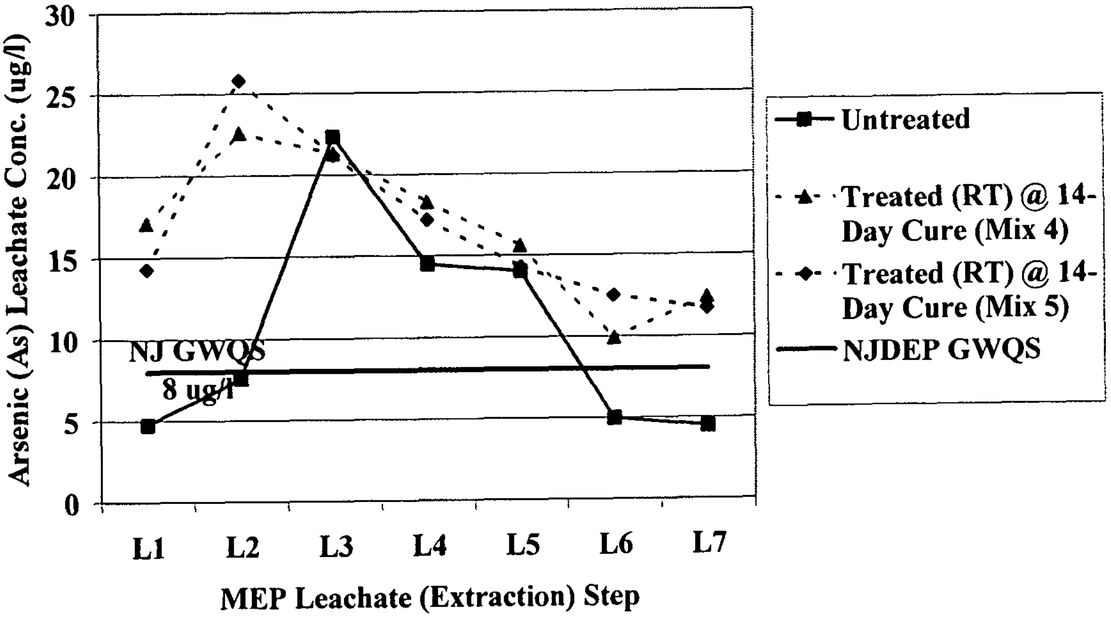
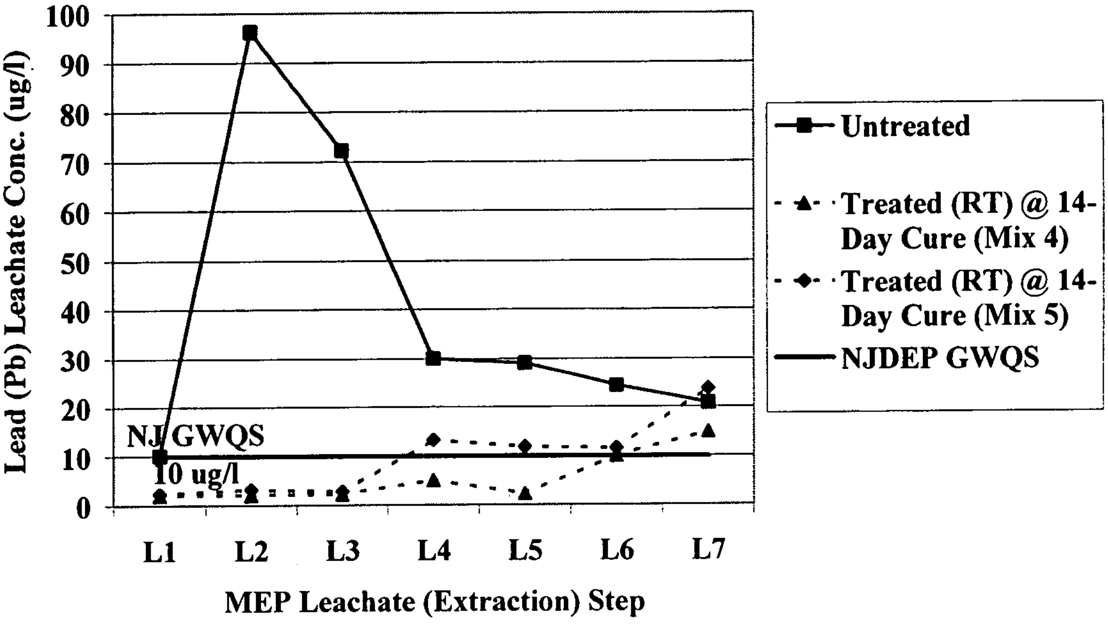


Figure 6-19: MEP Leachate Results for Untreated and Treated Stratus Material [Lead] – Mix 4 and Mix 5



The following observations were made from the MEP leachate results for metals (arsenic and lead only) for the Stratus material treated using Mix 4 and Mix 5:

- After the 14-day curing period, the material treated with both Mix 4 and Mix 5 shows better stabilization of lead (Pb) contamination as compared to arsenic (As);
- Although a significant reduction and general delay is observed in the leaching of lead (Pb) contamination during seven (7) MEP extraction steps, a general increase is noted in the leaching of arsenic (As) contamination as compared to the untreated material for both Mix 4 and Mix 5;
- Both Mix 4 and Mix 5 were unsuccessful in reducing the leaching of the arsenic (As) and lead (Pb) contamination below the NJDEP GWQS during all seven (7) extraction steps of the MEP procedure.

6.2 Georemediation™ Reagent Mix/Loading Rate Selection

Georemediation™ reagent mixes are designed using various reactive, basic, and inorganic substrates including portland cement, fly ash, and/or blast furnace slag, modified by the addition of transition metal salts, oxidants, clay pillaring agents and dispersants. The selection of various components of a Georemediation™ mix, their compositional distribution, and loading rate (percent by wet weight of sediments) are dependent upon a number of factors including, but not limited to the physical and chemical characterization of the contaminated material, desired end-product characteristics, and economics.

A list of Georemediation™ mix types (Mix 1 through Mix 5) tested during this pilot study and their compositional distribution is previously presented in Table 5-8 in Section 5.7. The table also provides estimated density of the mixes based on laboratory measurements, which will likely impact the geotechnical properties of the treated material.

The following presents a brief summary of the steps taken for the initial selection and subsequent modifications and additions to obtain the most chemically effective Georemediation™ reagent mix type and loading rate during this pilot study:

- Initially, Georemediation™ Mix 1 and Mix 2 were designed based on the untreated Stratus material characterization results and tested during the first round of the bench-scale treatment. The mixes were designed primarily based on the known presence of dioxins/furans and very low levels of PAHs contaminants in the Stratus material, exceeding the applicable upland beneficial use regulatory criteria;
- The two mixes (Mix 1 and Mix 2) primarily differed in their source of smectite clay (blast furnace slag and fly ash, respectively), which would likely provide different chemical and geotechnical characteristics of the treated material;
- The loading rate (percent by wet weight of sediments) for the first round of bench-scale testing on Stratus material was selected as 10% and 20%, based on past experience with their effectiveness and economic considerations;
- Although, only dioxins/furans analysis was performed during first round of bench-scale testing on Stratus material, the results indicated significant positive reductions for both mix types and loading rates, with Mix 2 at 10% loading providing the most promising results;

why not PAH

- Subsequent to BEM's procurement of additional dredged material, the two mixes (Mix 1 and Mix 2) were also used for the first round of bench-scale testing of the Tremley Point material with levels of organic contaminants (i.e. PAHs, dioxins/furans) similar to those detected in Stratus material. However, the Tremley Point material also contained low levels of other organic contaminants (i.e. pesticides, PCBs). In addition, arsenic (As) was detected above the applicable regulatory criteria for upland beneficial use (NJDEP RDCSCC);
- The results of the first round of Tremley Point bench-scale test results indicated positive reductions in organic contaminants (i.e. PAHs, Pesticides, and PCBs) for Georemediation™ Mix 2 at 10% loading rate. However, both Mix 1 and Mix 2 were largely unsuccessful in significantly reducing the total metal contaminants, including arsenic (As) which remained above the NJDEP RDCSCC after treatment;
- Consequently, Georemediation™ Mix 2 at 10% loading was deemed to be most chemically effective, and selected for the pilot treatment stage, largely based on the dioxins/furans

results from the first round of bench-scale testing on Stratus material, and supported by Tremley Point bench-scale results for organics;

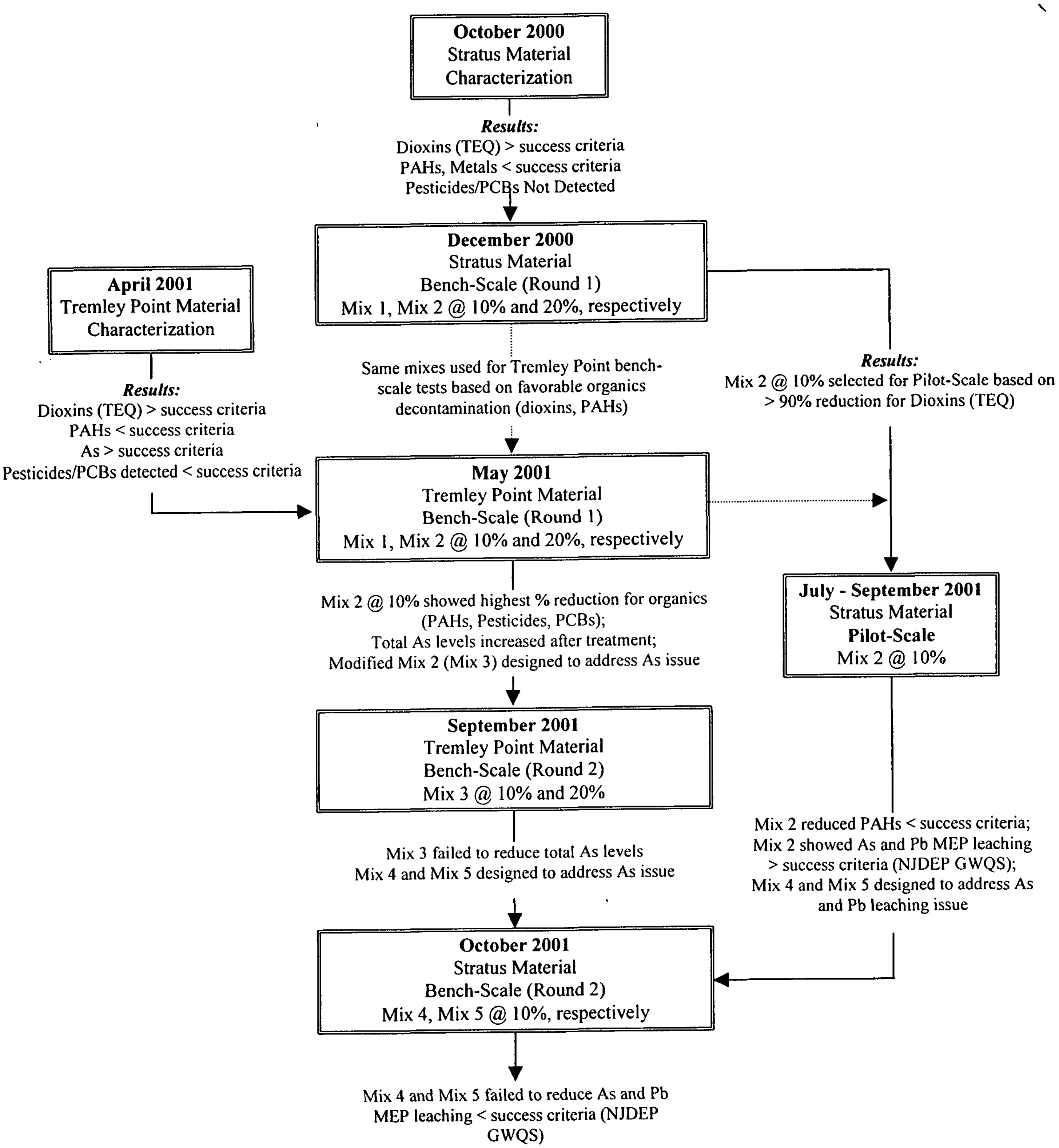
- Although the pilot treatment results showed consistent reductions in PAHs ~~results,~~ low to negative percent reductions were observed for metal contaminants, especially arsenic (As). In addition, arsenic (As) and lead (Pb) were shown to leach above the NJDEP GWQS during the MEP leaching test. However, the dioxins/furans results at the pilot stage were deemed largely inconclusive due to difficulties encountered by the analytical laboratory in analyzing the dioxins, thereby severely jeopardizing the credibility of the data (Section 6.3);
- The second round of bench-scale testing on Tremley Point was conducted by modifying the previously used Mix 2, with the addition of phosphoric acid (H_3PO_4) in an attempt to further stabilize the arsenic (As) contaminant. The modified mix (Mix 3) was largely unsuccessful in improving the effectiveness of the treatment to reduce metal contamination, specifically arsenic (As);

?

- Alternative source of smectite clay (Neucem) was used to design and test new mixes (Mix 4 and Mix 5) along with alternative transition metal catalysts. However, Mix 4 and Mix 5 were largely unsuccessful in achieving the chemical effectiveness success criteria of reducing the total metal concentrations below the NJDEP RDCSCC and metals concentrations in the MEP leachate below the NJDEP GWQS, for unrestricted upland use.

Figure 6-20 presents a flow-chart summarizing the decision making process for the selection of various Georemediation^{TM} reagents and the sequence of various bench-scale tests, and the pilot-scale test using the selected Mix 2 at 10% loading.

Figure 6-20: Decision Making Process and Sequence of Various Bench-Scale Tests on Stratus and Tremley Point Material and Pilot-Scale Test on Stratus Material



6.3 Laboratory Analytical Issues – Dioxins/Furans Analysis

The dioxins/furans analysis for all samples collected during this pilot study was conducted by Paradigm Analytical Laboratories, Inc. of Wilmington, North Carolina. Paradigm conducted the analysis under a subcontractor agreement with Accutest Laboratories of Dayton, New Jersey, a direct subcontractor to BEM for the analytical services for this pilot study.

All dioxin/furans analysis was conducted using the EPA standard method SW846 8290, as specified in BEM's workplan dated 03 May 2000. However, the integrity, usefulness, and the relevance of the dioxins/furans data to achieve the objectives of the pilot study was severely jeopardized due to series of events that resulted in inaccurate dioxins/furans data available to BEM at critical decision making stages. The following provides a brief summary of these events, followed by detailed discussion of the dioxins/furans data received from Paradigm laboratory:

- As part of the initial untreated Stratus material characterization in October 2000, triplicate samples analysis indicated an average total dioxins/furans concentration (TEQ) of 202 ppt. As part of the SW846 8290 method, Paradigm used "Soxhlet" extraction for the extraction of dioxins/furans from the contaminated matrix prior to the instrumentation analysis;
- For the samples collected after the initial characterization sampling, Paradigm switched to an "Automatic Solvent Extraction" (ASE), also approved under the SW84 8290 method for dioxins/furans analysis;
- A comparison of the "ASE" extracted bench-scale treated Stratus samples (Round 1) with the "Soxhlet" extracted untreated samples (initial) suggested significant reductions in dioxins/furans contamination for both Mix 1 and Mix 2, with > 90% reduction for Mix 2 at 10% loading;
- Since no other significant contamination above the applicable regulatory criteria was detected in Stratus material, the selection of the Georemediation™ mix (Mix 2) for the pilot treatment stage was largely based on the results of the dioxins/furans at the bench-scale treatment. However, as later determined by Paradigm through duplicate analyses, "ASE" extracted samples provided dioxins/furans results biased considerably lower than the "Soxhlet" extracted samples;
- A significant number of samples were submitted to Paradigm laboratories for dioxins/furans analysis during the pilot treatment stage from material treated under five (5) different treatment and curing conditions after 14- and 28-day curing periods. In addition, duplicate samples for the untreated Stratus material were analyzed for dioxins/furans, as part of the re-characterization of the Stratus material. However, the "ASE" extracted results of these samples were highly erratic and showed considerably poor replication. In addition, the results were inconsistent with the results previously observed at the bench-scale level for similar treatment conditions;
- The poor replication and inconsistencies in the data for pilot treated samples subsequently surfaced in some of Paradigm's internal re-runs of several samples due to internal laboratory QC checks, with upto an order of magnitude difference in total TEQ values between re-runs;
- In August 2001, upon, BEM's request, Paradigm re-analyzed all pilot treated samples and untreated re-characterization samples, previously analyzed using the "ASE" extraction, with

the "Soxhlet" extraction, which is accepted as more aggressive as compared to "ASE" extraction;

- The re-analysis data based on "Soxhlet" extraction showed slightly improved, yet unacceptable replication as compared to "ASE" extracted sample results, and in general showed much higher concentrations of dioxins/furans as compared to "ASE" extracted sample results. This resulted in much lower percent reductions suggested for the material treated using Georemediation^{TM} Mix 2;
- Although, Mix 2 may be largely ineffective for dioxins/furans contamination, further modification or improvement of the mix was not possible due to misleading results, which were largely inconsistent, despite the re-analysis with the "Soxhlet" extraction;

A comparison of the dioxins/furans results for all samples analyzed using both "Soxhlet" and "ASE" extraction during this pilot study is presented in the analytical data tables in Appendix B-13. The data tables also present the replication (relative percent difference [RPD]) between the duplicates analyzed using a specific extraction procedure ("Soxhlet" or "ASE") and a relative percent difference (RPD) between the average values for the two extraction procedures for the same sample. A summary of this analysis is presented in Table 6-16 using only the total TEQ values.

Table 6-16: Comparison of "ASE" and "Soxhlet" Extraction Based Dioxins/Furans Results

Sample Identification	Dioxins/Furans (Total TEQ Results) – "ASE" Extraction[a]				Dioxins/Furans (Total TEQ Results) – "Soxhlet" Extraction[a]				RPD$_{1-2}$[b] (%)
	Run 1	Run 2	Avg.$_{1}$	RPD$_1$[b] (%)	Run 1	Run 2	Avg.$_{2}$	RPD$_2$[b] (%)	
SEU4									
SEM21014-RT	11.8	11.9	11.9	-1%	70.8	118.0	94.4	-50%	-155%
SEM21014-RH	5.2	23.0	14.1	-126%	78.8	91.3	85.1	-15%	-143%
SEM21014-FR	59.4	67.7	63.6	-13%	48.6	61.7	55.2	-24%	14%
SEM21014-DRY	79.0	113.0	96.0	-35%	159.0	164.0	161.5	-3%	-51%
SEM21014-DPA	88.1	117	102.6	-28%	165.0	209.0	187.0	-24%	-58%
SEM21014-DPB	208.0	126.0	167.0	49%	152.0	184.0	168.0	-19%	-1%
SEM21014-DPC	197.0	125.0	161.0	45%	171.0	168.0	169.5	2%	-5%
SEM21028-RT	18.1	90.6	54.4	-133%	453.0	178.0	315.5	87%	-141%
SEM21028-RH	98.4	58.2	78.3	51%	207.0	140.0	173.5	39%	-76%
SEM21028-FR	62.6	13.4	38.0	129%	127.0	157.0	142.0	-21%	-116%
SEM21028-DRY	66.8	107.0	86.9	-46%	168.0	131.0	149.5	25%	-53%
SEM21028-DPA	53.6	69.7	61.7	-26%	121.0	120.0	120.5	1%	-65%
SEM21028-DPB	97.4	59.0	78.2	49%	137.0	233.0	185.0	-52%	-81%
SEM21028-DPC	30.40	46.80	38.60	-42%	166.0	157.0	161.5	6%	-123%

[a] Shaded cells indicate total TEQ values greater than 50 ppt (ATSDR guidance value)

[b] Shaded cells indicate relative percent difference (RPD) values > |±20%| and considered unacceptable. RPD values are calculated as: ((1st Value - 2nd Value)/Average Value) x 100%; RPD$_{1-2}$ represents relative percent difference between RPD$_1$ and RPD$_2$ values

The following observations were made from the results presented in Table 6-16 and Appendix B-13:

- Poor replication was observed (RPD$_1$ > |±20%|) in samples analyzed using the "ASE" extraction method, with variations as high as –133%;

- Although, slightly better than "ASE" extraction data, relatively poor replication was also observed ($RPD_2 > |\pm 20\%|$) for the re-analyzed samples using "Soxhlet" extraction, with variations as high as 87%;
- Average values using "ASE" extraction were biased considerably lower as compared to values based on "Soxhlet" extraction ($RPD_{1\text{-}2}$ consistently negative and as high as –155%);
- The results of both "ASE" and "Soxhlet" extraction show a general ineffectiveness of the Georemediation™ Mix 2 to reduce to dioxins/furans contamination (total TEQ) below 50 ppt (ATSDR guidance value), considered as the chemical decontamination success criteria.

The inaccurate results provided by Paradigm during bench-scale testing of the Stratus material did not allow BEM with an opportunity to further modify and test Georemediation™ reagent at the bench-scale to properly determine its effectiveness on dioxins/furans contamination. In addition, the conclusions drawn from the pilot treatment stage were severely limited due to lack of observable trends in the dioxins/furans results. Therefore, subsequent to the re-analysis of all pilot treated samples by Paradigm using "Soxhlet" extraction, and resolution of the analytical data, BEM conducted additional bench-scale testing on the Stratus material using Georemediation™ Mix 4 and Mix 5. The results of these tests are presented in Section 6.1.2.4. All samples collected during additional bench-scale tests were analyzed using the "Soxhlet" extraction, which is considered to be more aggressive extraction procedure, and better representative of the dioxins/furans contamination present in the matrix.

6.4 Geotechnical Testing

The untreated and treated Stratus material samples were tested for geotechnical properties at Rutgers, CAIT laboratories under the supervision of Dr. Ali Maher of Soiltek, Inc., using the methods and procedures outlined in Section 5.11. The testing was conducted to evaluate the geotechnical suitability of the Georemediation™ treated material for the anticipated beneficial use options listed in Section 4.2.

The following re-summarizes the three (3) treatment conditions for the treated material used for geotechnical testing:

- Mix 1: Stratus material treated using Georemediation™ Mix 1 at 10% loading by wet weight of untreated sediments, applied as a reagent slurry using 1:1 reagent to water ratio;
- Mix 2 [RT]: Stratus material treated using Georemediation™ Mix 2 at 10% loading by wet weight of untreated sediments, applied as a reagent slurry using 1:1 reagent to water ratio;
- Mix 2 [DRY]: Stratus material treated using Georemediation™ Mix 2 at 10% by wet weight of untreated sediments, applied as a dry reagent powder (without any additional water).

The following sections present the results of the geotechnical tests performed on the untreated and three (3) Georemediation™ treated Stratus material samples.

6.4.1 Solidification

An important parameter for field placement of the treated dredge material is the solidification of the material. This is described as the process of eliminating excess water from the soil mass by hydration with the addition of a setting agent. The solidification of the material is determined by measuring the decrease of moisture content versus time from the point immediately after mixing. The material is allowed to dehydrate until a specific moisture content is reached, usually a moisture content used for field compaction. In the case of this study, the moisture content was that at which the unit weight of the material could be compacted to 90% of the maximum dry density on the wet side of the compaction curve. Table 6-17 shows the results from the solidification test. The moisture content degradation curves are provided in Appendix C-1.

Table 6-17: Solidification Test Parameters

Georemediaton™ Treatment	Target Moisture Content[a] (%)	Time for Solidification (days)
Mix 1	59	24
Mix 2 [RT]	38.5	34
Mix 2 [DRY]	36	43

[a] Target moisture content represents moisture content to achieve 90% of the maximum dry density on the wet side of the compaction curve

As shown in Table 6-17, utilizing Mix 1 allows for the dredge material to dewater faster. However, this may be somewhat misleading when comparing the target moisture contents. Mix 1 has a target moisture content 20% higher than Mix 2 [RT] and 23% higher than Mix 2 [DRY]. Although Mix 1 may reach its compaction moisture content quicker than the other 2 mixes, the elevated compaction moisture content may compromise the other geotechnical properties of the material (i.e. CBR, unconfined compression, etc.), as will be shown later in the report.

6.4.2 Specific Gravity (ASTM D854)

Specific gravity tests were conducted on both the untreated and treated Stratus materials. The results of the testing are shown in Table 6-18. In addition, approximate specific gravity of the Georemediation^{TM} regent mixes, as measured in the laboratory are also presented in Table 6-18.

Table 6-18 : Specific Gravity Test Results

Georemediation^{TM} Treatment	Specific Gravity (Untreated/Treated Material)	Specific Gravity (Georemediation^{TM} Mixes)[a]
Untreated	2.522	N/A
Mix 1	2.594	1.29
Mix 2 [RT]	2.518	1.04
Mix 2 [DRY]	2.572	1.04

[a] Calculated based on density values measure in the laboratory and presented in Section 5.7 (water density of 62.4 lbm/ft^3 assumed for the calculations)

6.4.3 Grain Size Analysis (ASTM D422)

Standard sieve analysis tests were conducted on representative samples that had been retained while washing the material through a No. 200 (75 micron) sieve. Hydrometer tests were also conducted on representative samples that had been dry sieved through a No. 200 sieve. Combining the data allowed for the determination of a grain size curve that could represent the material from gravel to clay. The average results of the testing program are shown in Table 6-19. Individual test results, along with their respective curves, are provided in Appendix C-2.

From the results, it can be determined that Mix 1 provides a more "cement-like" bonding of soil particles than the other mixes used. Evidence of such a reaction is the increase in % Sand from the raw dredge material's 7.3% to the 15.7% for the Mix 1 (wt). Mix 1 also shows a decrease in the % Clay, as the particle size increases to a silt material. The D_{50} (average particle size) of the Mix 1 is also the largest. As for the other 2 mixes, this type of "cement-like" reaction does not seem to exist and the material resembles that of the untreated dredge sediment. These observations may be correlated to the compositional distribution of the Georemediation^{TM} reagent mixes presented in Section 5.7. Both Mix 1 and Mix 2 contain same amount of portland cement (50% by weight). However, Mix 1 contains steel blast furnace slag, which exhibits "cement-like" characteristics, fly ash in the Mix 2.

Table 6-19: Grain Size Characteristics

Georemediation^{TM} Treatment	% Gravel	% Sand	% Silt	% Clay	D_{50} (mm)
Untreated	0.1	7.3	63.7	28.9	0.012
Mix 1	0.0	15.7	66.3	18	0.016
Mix 2 [RT]	0.0	6.1	69.3	24.6	0.0113
Mix 2 [DRY]	0.0	7.7	61.6	30.7	0.0104

6.4.4 Atterberg Limits (ASTM D4318)

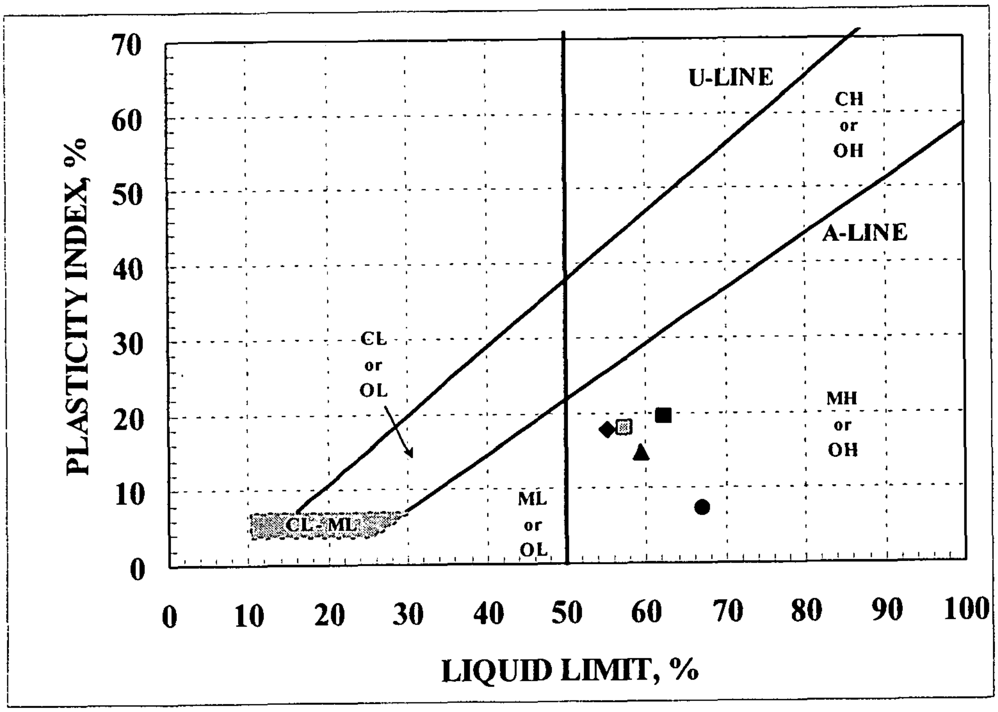
The Atterberg limit test is used to index fine-grained soils based on material behavior at different moisture contents. The index testing is also utilized to aid in the classification of fine-grained soils. The tests were conducted on all three treated samples, as well as the untreated Stratus material. The untreated Stratus material was tested under both air and oven-dried conditions. Under the test specifications, if the ratio of the oven-dried to the air-dried liquid limit is less than 85%, the material is considered to be organic.

Based on the results, the untreated Stratus material just passes the criteria of not being organic. Results from the testing are shown in Table 6-20 and Figure 6-21. The material is generally classified, under the USCS classification system, as elastic silt (MH).

Table 6-20: Atterberg Limit Test Results

Georemediation^{TM} Treatment	Liquid Limit	Plastic Limit	Plasticity Index	Symbol
Untreated (Air Dried)	62.4	43	19.4	■
Untreated (Oven Dried)	57.3	39.4	17.9	▨
Mix 1	67	59.8	7.2	●
Mix 2 [RT]	59.4	44.6	14.8	▲
Mix 3 (dry)	55.1	37.3	17.8	◆

Figure 6-21: USCS Liquid Limit/Plasticity Index Chart



All the samples tested are below A-line and to the right of LL=50 line on plasticity chart as shown in Figure 6-21. Therefore, the material could be classified as Elastic Silt (MH). The treated materials do not change much from the untreated Stratus material, except for Mix 1. The decrease in plasticity index [from 17.9 of the untreated dredge to 7.2 for the Mix 1] illustrates the effect of a cement/pozzolanic admixture. The reduction in plasticity index provides a more workable material, as well as a material less prone to volume changes due to moisture content variations. The shrinkage limit was approximately 50% based on previous experiments on the untreated material.

6.4.5 Modified Compaction Test (ASTM D1557)

Modified compaction tests were conducted on the treated Stratus material to comply with AASHTO recommendations for the use of fine-grained soils in roadway applications. The results were used to determine the target unit weight and moisture contents that test samples were to be compacted to (90% of the maximum dry density on the wet side of the compaction curve). The results from the modified compaction tests are shown in Table 6-21, with the compaction curves for the individual material included in Appendix C-3. γ_{dmax} is noted as the maximum dry density and $W_{\%OPT}$ is the optimum moisture content.

Table 6-21: Modified Compaction Test Results

Georemediation™ Treatment	γ_{dmax} (lb/ft^3)	$W_{\%OPT}$ (%)	90% of γ_{dmax} (lb/ft^3)[a]	W% at 90% of γ_{dmax} (%)
Mix 1	66.6	49.7	60	59
Mix 2 [RT]	86	24	77.4	37
Mix 2 [DRY]	87.6	28.9	78.8	35.5
SDM (8% PC)[b]	76.6	31.5	69	48.5

[a] Typical dry unit weights for MH sub-grade material are 80-100 PCF (Yoder and Witczak 1975)

[b] Represents typical Solidified Dredged Material (SDM) using 8% Portland Cement (by weight of the wet material)

The 90% of γ_{dmax} and the W% at 90% of γ_{dmax} are the target density and moisture content values, respectively, used for the compaction of all samples prior to the testing. The 90% parameter represents a conservative value that may occur if field compaction and quality controls are average to poor. As shown in Table 6-21, the Mix 1 treatment produces a much lower dry density than the other two mix types. The lower dry density would most likely create a softer, more compressible material in the field with geotechnical properties that are not desirable for roadway sub-grade and structural fill material.

6.4.6 California Bearing Ratio (ASTM D1883)

California Bearing Ratio (CBR) tests were conducted on samples compacted to 90% of the maximum dry density on the wet side of the curve. However, very low results were encountered at this unit weight. Therefore, for comparison purposes, CBR tests were also conducted on three (3) treated samples at approximately 98% of the maximum dry density on the wet side. The additional testing was for the illustration of the treated material's ability to sustain a design CBR value at a higher level of compaction. Table 6-22 shows the CBR values obtained with the corresponding compaction for the mixes tested. The actual CBR load versus deformation curves for all samples tested are included in Appendix C-4.

The CBR value is strongly influenced by the compaction of the material (i.e. the more dense the compaction, the higher the CBR value). Therefore, it is not surprising to see that Mix 1 obtained the lowest CBR value when compacted to the target density, with both Mix 2 [RT] and Mix 2 [DRY] obtaining identical values of 2.2. However, when the material was compacted to 98% of the maximum dry density, the CBR values are much higher.

Table 6-22: California Bearing Ratio Test Results

Georemediation™ Treatment	Compacted Dry Density (lb/ft^3)	Compacted Moisture Content (%)	CBR Value[a]
Mix 1 [90%]	54.5	59.8	0.9
Mix 1 [98%]	56.6	50.3	20.9
Mix 2 [RT] [90%]	70.3	37.1	2.2
Mix 2 [RT] [98%]	82.7	32.4	10.8
Mix 2 [DRY] [90%]	70.9	37.1	2.2
Mix 2 [DRY] [98%]	78.8	36.7	7.8

[a] Typical CBR values for MH sub-grade material are 4-8 (Yoder and Witczak, 1975)

6.4.7 Unconfined Compression Test (ASTM D2166)

To determine the undrained shear strength of the treated Stratus material, unconfined compression tests were conducted on molded samples. All molded samples were compacted following the specifications for the compaction of fine-grained samples for resilient modulus testing (AASHTO T307). All samples were compacted to their respective target 90% of maximum dry density on the wet side as previously shown in Table 6-21. Table 6-23 shows the average unconfined compression results for all three (3) treated Stratus materials tested. The sample test results are included in Appendix C-5.

Table 6-23: Unconfined Compression Test Results

Georemediation™ Treatment	Compressive Strength (lb/ft^2)[a]	Failure Strain (%)	Undrained Shear Strength (lb/ft^2)
Mix 1	2,057.2	2.4	1,028.1
Mix 2 [RT]	2,825.0	4.1	1,412.5
Mix 2 [DRY]	8,863.3	3.8	4,431.7

[a] Typical Compressive Strength (lb/ft^2) values:

Medium Clays:	1,000-2,000
Stiff Clays:	2,000-4,000
Very Stiff Clays:	4,000-8,000

Mix 2 [DRY] obtained the highest compressive strength, more than three times that of the Mix 2 [RT] and four times higher than Mix 1 (dry). The compressive strength is relatively proportional to the compacted target dry density (i.e. as the compacted target dry density increases so does the compressive strength). The compressive strength values are somewhat lower than typical soil-cement or cement modified soils and the material may needs to be further modified by cement to achieve higher strengths.

6.4.8 Swell Potential (ASTM D4546)

Swell Potential tests were conducted on the treated Stratus material to determine if the material would be susceptible to swelling when introduced to water above the moisture at which it was compacted. All samples were compacted to 90% of their respective maximum dry density (on the wet side). These target densities are as previously shown in Table 6-21. Actual compaction dry densities, with their respective moisture contents, are shown in Table 6-24 with the average swell pressure for all samples tested. Individual results are included in Appendix C-6.

Table 6-24: Swell Potential Test Results

Georemediation™ Treatment	Dry Density (lb/ft^3)	Moisture Content (%)	Swell Pressure (lb/ft^2)	Percent Swell (%)
Mix 1	59.8	59.8	187	0.47
Mix 2 [RT]	76.7	39.1	320	0.9
Mix 2 [DRY]	79.2	36	1,280	2.4

The swell potential results show Mix 2 [DRY] has the greatest potential for swell when water is introduced to the compacted material. It should also be noted that the samples were compacted at higher moisture contents then may be achieved during compaction in the field. Typically, as the material becomes dryer, the swell potential becomes larger.

The laboratory data indicates several trends. The strain or percent swell was not significant for any of the samples tested. The strain values ranged from 0.47 to 2.4 percent, with an average of 1.3 percent. The maximum strain was observed for material treated using Mix 2 [DRY]. However, this magnitude of volume change is considered low and, therefore, not detrimental to adjacent structures. These laboratory results counter the probable expansion information provided by Holtz and Novak (1981), and referenced in Table 6-25.

Table 6-25: Probable expansion estimated from Classification Data

(Adopted after Holtz and Kovacs, 1981)

Degree of Expansion	Probable Expansion as a % of the total volume change (dry to saturated condition)
Very High	> 30
High	20-30
Medium	10-20
Low	<10

6.4.9 Collapse Potential (ASTM D5333)

The Collapse Potential of each treated material was determined in the laboratory for three different possible applied load applications. The collapse potential represents how the material may deform after water is introduced to the compacted material that has a constant load already applied to the material. This could possibly represent a sub-grade soil under a heavy rainfall. Load #1 (240 lb/ft^2) corresponds to a thin pavement section with the treated Stratus material used as a sub-grade soil. Load #2 (500 lb/ft^2) corresponds to a thick pavement section with the treated Stratus material used as a sub-grade soil. Load #3 (2000 lb/ft^2) was arbitrarily chosen as 1 ton/ft^2, which is four times greater than Load #2. Collapse Potential results are shown in Table 6-26 and are depicted as the percent of sample deformation due to the introduction of water after 24 hours of soaking. Load-deformation curves for the individual samples are included in Appendix C-7.

Table 6-26: Collapse Potential Results

Georemediation™ Treatment	Dry Density (lb/ft^3)	Moisture Content (%)	% of Sample Collapse (%)
Mix 1 [Load #1]	60.1	60.7	0.1
Mix 1 [Load #2]	60.3	60.7	0.2
Mix 1 [Load #3]	60.6	60.7	0.3
Mix 2 [RT] [Load #1]	76.6	39.8	0.06
Mix 2 [RT] [Load #2]	76.6	39.8	0.2
Mix 2 [RT] [Load #3]	76.9	39.8	0.3
Mix 2 [DRY] [Load #1]	77.7	37.8	-0.1
Mix 2 [DRY] [Load #2]	77.9	37.8	-0.1
Mix 2 [DRY] [Load #3]	77.6	37.8	0.07

The results indicate that the material is not prone to collapse under the particular compaction and loading characteristics tested in this study. In fact, the first two loading schemes for Mix 2 [DRY] actually caused a swelling effect, thereby showing a negative % collapse. This also provides evidence of the higher swelling potential exhibited earlier in the swell potential tests for Mix 2 [DRY].

6.4.10 Permeability (ASTM D5084)

Flexi-wall permeability tests were conducted on the treated Stratus material to determine the hydraulic conductivity of the compacted sample when inundated with tap water, which was used as the permeate medium. The samples were first back-saturated to ensure that the saturation of the samples was approximately 100%. The individual samples were also tested as varying hydraulic gradients ($\Delta h/L$) to examine if the material's hydraulic conductivity (k) was strongly influenced by the hydraulic gradient induced during the permeability test. The test results are shown in Table 6-27, along with properties of the compacted samples tested.

Table 6-27: Permeability Test Results

Georemediation™ Treatment	Dry Density (lb/ft^3)	Moisture Content (%)	Void Ratio (e)	$\Delta h/L$	k (cm/s)
Mix 1	60	59.4	1.69	16.7	3.77×10^{-6}
Mix 1	59.5	59.1	1.72	9.7	3.48×10^{-6}
Mix 1	59.2	59.1	1.73	4.2	3.81×10^{-6}
Mix 2 [RT]	76.2	38.4	1.06	16.5	1.21×10^{-6}
Mix 2 [RT]	76.2	38.4	1.06	10	1.37×10^{-6}
Mix 2 [RT]	76.6	38.4	1.05	4	1.12×10^{-6}

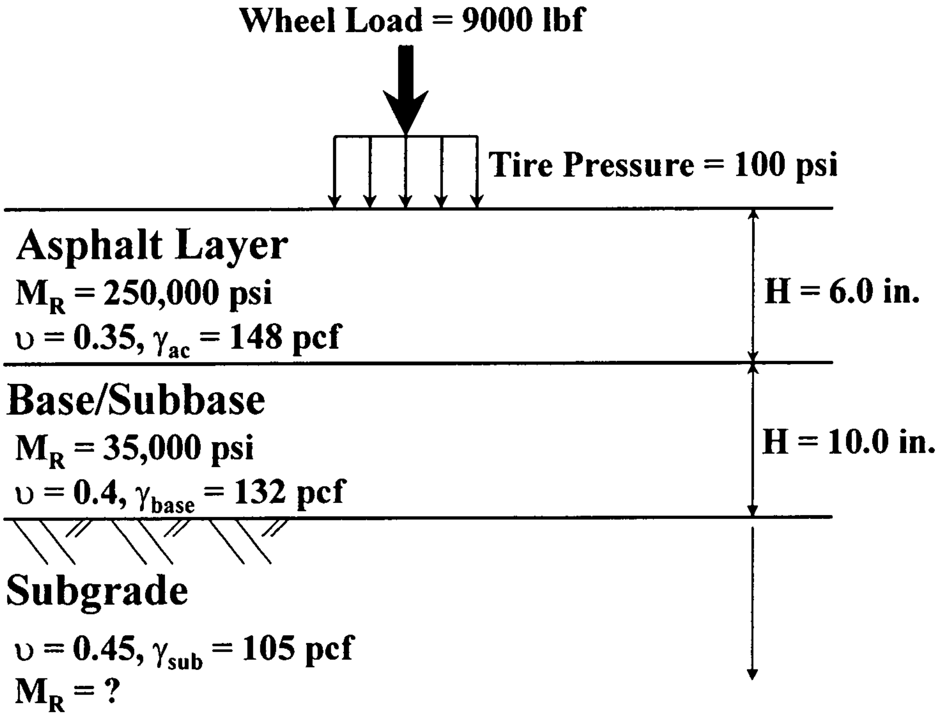
Georemediation™ Treatment	Dry Density (lb/ft^3)	Moisture Content (%)	Void Ratio (e)	Δh/L	k (cm/s)
Mix 2 [DRY]	76.2	37.8	1.1	16.8	7.18×10^{-7}
Mix 2 [DRY]	76.6	37.8	1.09	5.6	7.83×10^{-7}
Mix 2 [DRY]	76.4	37.8	1.1	4	7.2×10^{-7}

The general trend of the permeability results conform to the % Clay content and the average particle size of the material – D_{50} (i.e. Mix 1 – largest D_{50}, lowest % Clay, highest permeability value; Mix 2 [DRY] – smallest D_{50}, highest % Clay, lowest permeability value).

6.4.11 Resilient Modulus (AASHTO TP46-94)

Resilient Modulus tests were conducted on compacted samples of the treated material. The resilient modulus (M_r) is currently used as "the" index parameter for pavement design and is used as a direct input parameter in pavement design models. However, since the M_r is a stress dependent parameter, it is not possible to give one "resilient modulus value". Therefore, the average resilient modulus values used for comparison in Table 6-28 are for the pavement section/stress condition depicted in Figure 6-22. For comparison purposes, the typical pavement section (Figure 6-19) was developed and analyzed using elastic layered theory to determine the bulk stress and deviatoric stress due to an 18 kip applied axle load. The results were as follows:

Figure 6-22: Typical Pavement Section for Resilient Modulus Determination



Bulk Stress (θ) = 9.1 psi
Applied Deviatoric Stress (σd) = 5.0 psi

The individual regression equations for each sample tested are included in Appendix C-8.

Table 6-28: Resilient Modulus Test Results

Georemediation™ Treatment	Dry Density (lb/ft³)	Moisture Content (%)	Resilient Modulus (lb/ft³)
Mix 1	59	59.1	1,793.4
Mix 2 [RT]	76.5	38.4	3,293.4
Mix 2 [DRY]	76.7	37.6	8,534.3
New Jersey Rt. 285 (Silty Sand) [Max. Dry Density]			6,405.8
New Jersey Rt. 206 (Silt with Fine Sand) [Max. Dry Density]			6,554.3
New Jersey Rt. 23 (Medium to Fine Sand) [Max. Dry Density]			9,633.5

The results indicate that Mix 2 [DRY] provides the highest resilient modulus value, with Mix 2 [RT] achieving somewhat lower values. This trend is consistent with the unconfined compression tests. Mix 1 had difficulties during the higher bulk stress sequences due to its soft/compressible nature, and in the case of one of the samples, failed during the testing. Therefore, the regression analysis conducted on the material only consists of lower bulk stress levels for two samples and may be adequate for design purposes.

6.4.12 Freeze-Thaw Testing (ASTM D560)

Compacted samples of the treated Stratus material were exposed to freeze-thaw cycling to determine if the compacted mixtures were susceptible to degradation upon freeze-thaw cycling. The results shown in Table 6-29 are represented by the % volume that was lost due to the cycling process. Each full cycle lasted 48 hours, 24 hours under freezing conditions, 23 hours thawing, and then one hour for the scraping process. The cycle at sample failure, which is being defined when 50% or more of the sample is lost, is also indicated. The maximum testing period under the testing specifications is 12 cycles.

Table 6-29: Freeze-Thaw Susceptibility Test Results

Georemediation™ Treatment	Dry Density (lb/ft³)	Moisture Content (%)	Void Lost (%)	Failure Cycle
Mix 1	59.2	59.1	6.7	12*
Mix 2 [RT]	74.6	40.1	2.1	12*
Mix 2 [DRY]	76.7	37.8	24.7	4

* Maximum Number of Cycles for Test

Both Mix 1 and Mix 2 [RT] met the testing limits (12 cycles) with minimal volume loss, 6.7% and 2.1% respectively. However, Mix 2 [DRY] failed after only 4 cycles. The volume loss shown, 24.7%, is the volume loss before the end of the fourth cycle (3.5 cycles). During the scraping portion of the test cycle, each sample crumbled with no true recognizable sample remaining.

6.5 Process/Operational Testing Results

The following sections present the results of the air emissions and mechanical dewatering tests performed to address additional process and operational aspects of the Georemediation™ process.

6.5.1 Air Emissions Test Results

Air emissions testing was conducted on Stratus material treated with Georemediation™ Mix 2 and cured at room temperature ("RT" condition) following the procedures detailed in Section 5.12.1. The air emissions tests were used to evaluate the potential for unacceptable emissions of certain contaminants. The following sections present the detailed results of the air emissions testing.

6.5.1.1 Stratus Material Air Emissions Results – Round 1

The first round of air emissions tests on the Stratus material were conducted on 20 July 2001. The Georemediation™ Mix 2 was applied at a 10% loading (by wet weight of sediment material) in a slurry form with 1:1 reagent to water ratio to approximately 162 lbs of Stratus material ("RT" condition). Specific air emission analyses for VOCs, PCB, PAHs/SVOCs, and metals were performed to evaluate the pollutants that may potentially be emitted during the demonstration and full-scale treatment.

The first round of air emissions testing was conducted during the mixing and for the first 48 hours of the curing period.

The results from the first round of air emissions indicated no emissions for PCBs and metals were above the detection limits. In addition, only one of the SVOC compounds was detected above the detection limit. Therefore, air emissions at the full-scale level are not expected to exceed the major facility and the SOTA thresholds previously summarized in Table 4-2 in Section 4.2.

There were several low level VOCs emissions (in ppb range) were detected during the testing. Therefore, BEM anticipates a need for monitoring VOCs emissions at the demonstration or full-scale level. A summary of the VOCs compounds detected in the air samples collected is presented in Table 6-30. The complete analytical data tables providing all of the air emissions results of these samples are presented in Appendix D-1.

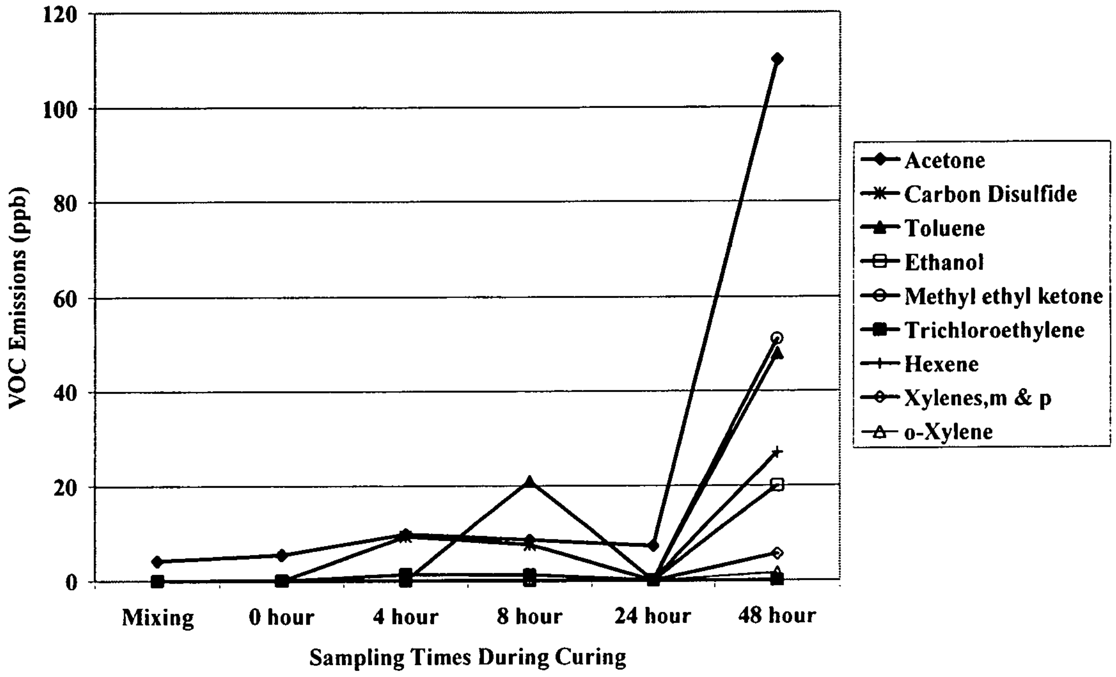
Table 6-30: Stratus Material Air Emissions Results (Detected VOCs) During 48-Hour Curing Period - Round 1

Parameter	Sampling Intervals During Curing Stage					
	Mixing	0 hr	4 hr	8 hr	24 hr	48 hr
Acetone	4.2	5.4	9.7	8.5	7.2	110
Carbon disulfide	ND	ND	9.2	7.5	ND	ND
Toluene	ND	ND	ND	21	ND	48
Ethanol	ND	ND	ND	ND	ND	20
Methyl ethyl ketone	ND	ND	ND	ND	ND	51
Trichloro-ethylene	ND	ND	1.3	1.2	ND	ND
Xylenes, m & p	ND	ND	ND	ND	ND	5.5
o-Xylene,	ND	ND	ND	ND	ND	1.6

ND – Not Detected

The results of selected target VOCs compounds for the first round of air emissions testing are also presented graphically in Figure 6-23. As indicated in the figure, peak conditions for VOCs emissions do not seem to have occurred during the 48-hour monitoring period. This data was deemed necessary to predict the period of maximum air emissions during the Georemediation™ treatment process. Therefore, a second round of air emissions testing was conducted for only VOCs emissions with longer monitoring period (96 hours).

Figure 6-23: Air Emissions Testing Results – Round 1 (48 Hour Curing Period)



6.5.1.2 Stratus Material Air Emissions Results – Round 2

The second round of air emissions testing on the Stratus material was conducted on 27 August 2001. The same Georemediation™ treatment conditions (RT) and material weight were used as previously used in Round 1 in order to allow for an added VOCs data comparison between the two rounds. Air emission analyses were conducted only for VOCs because the results from first round of testing did not indicate the emissions of PCBs, PAHs/SVOCs, and metals.

The second round of VOCs emissions testing was conducted for the first 96 hours of the curing period. A summary of the VOCs compounds detected in the air samples collected is presented in Table 6-31. The complete analytical data tables providing all of the air emissions results of these samples are presented in Appendix D-2.

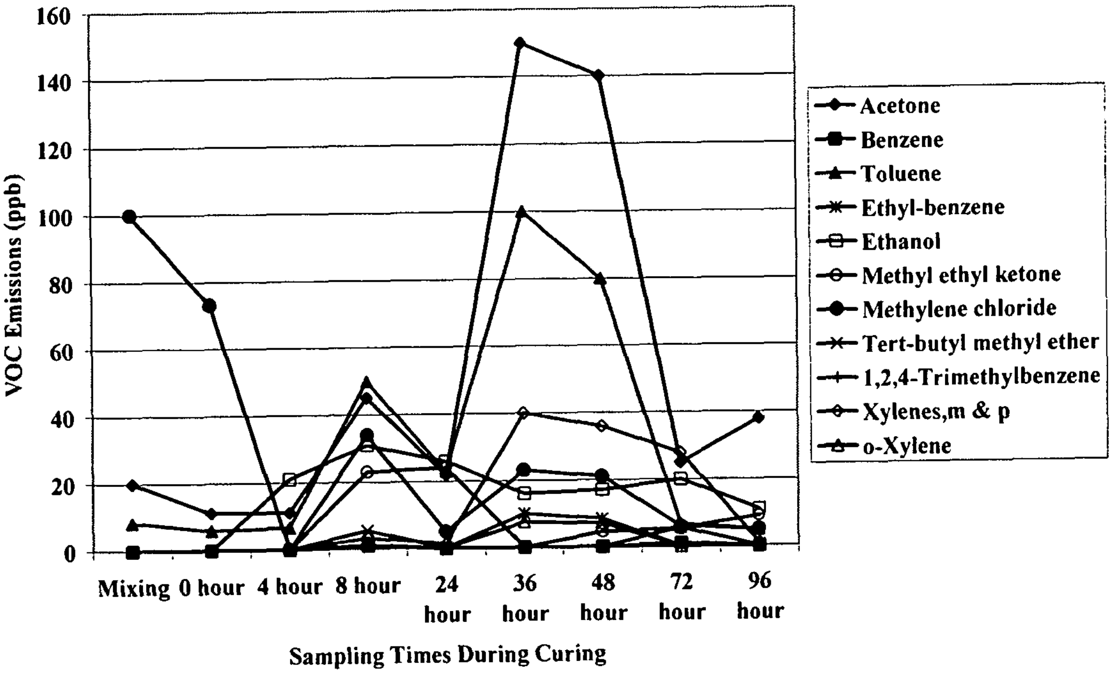
Table 6-31: Stratus Material Round 2 – Detected VOC Emissions Results (ppb) During 96-Hour Curing Period

Analyte	Sampling Intervals During Curing Stage								
	Mixing	0hr	4hr	8hr	24hr	36hr	48hr	72hr	96hr
Acetone	20	11	11	45	22	150	140	25	38
Benzene	ND	ND	ND	0.9	ND	ND	ND	0.9	ND
Toluene	8.2	5.8	6.5	50	23	100	80	6.6	4.8
Ethyl-benzene	ND	ND	ND	0.9	ND	10	8.3	ND	ND
Ethanol	ND	ND	21	31	26	16	17	20	11
Methyl ethyl ketone	ND	ND	ND	23	24	ND	4.4	5.1	9.0
Methlyene chloride	100	73	ND	34	4.9	23	21	5.8	4.9
Tert-Butyl methyl ether	ND	ND	ND	5.4	ND	ND	ND	5.5	ND
1,2,4-Trimethylbenezene	ND	ND	ND	1.0	ND	ND	ND	ND	ND
Xylenes, m & p	ND	ND	ND	3.2	1.4	40	36	28	0.85
o-Xylene,	ND	ND	ND	1.2	ND	7.5	7.0	ND	ND

ND – Not Detected

The results of selected target VOCs compounds for the second round of air emissions testing are presented graphically in Figure 6-24. Based on these second round VOC emission results, the data suggest that maximum VOC emissions occur within the first 96 hours of curing. After 96 hours of curing, it appears that VOC emissions decrease and steady-state conditions would be achieved.

Figure 6-24: Air Emissions Testing Results – Round 2 (96 Hour Curing Period)



6.5.2 Mechanical Dewatering Test Results

The mechanical dewatering tests were conducted by Komline-Sanderson of Peapack, NJ, on the untreated and Georemediation™ treated (RT) Stratus material. The tests were conducted to determine the need for dewatering the material prior to treatment and/or curing, and subsequently evaluate potential mechanical dewatering technologies. The procedures and methods used for the mechanical dewatering tests are detailed in Section 5.13. The following presents a summary of the results and conclusions based on the testing by Komline-Sanderson:

- Approximately 10-gallons of the untreated and Georemediation™ treated (RT) Stratus material samples were received by Komline-Sanderson at 45% and 44% total solids, respectively;
- The mechanical dewatering tests modeled Komline-Sanderson's belt filter press technology;
- Both untreated and treated samples showed dewatering potential. Untreated material dewatered from 45% total solids up to 57% total solids at an estimated rate of 2,800 lb hr^{-1} on a single GRS-2 Kompress® Belt Filter Press. However, the treated material dewatered only from 45% total solids up to 49% total solids at an estimated rate of 6,300 lb hr^{-1} on a single GRS-2 Kompress® Belt Filter Press;
- Untreated material failed the paint filter test (EPA Method 9095) prior to dewatering, thereby indicating the presence of free liquid;
- Treated material passed the paint filter test (EPA Method 9095) before and after the dewatering test, thereby indicating that no free liquid is anticipated from the Georemediation™ treated Stratus material with 44% total solids (127% Moisture Content);
- Two different polymers were used for the dewatering of the untreated Stratus material. However, no polymers or additives were required for the treated material, since the material was largely solidified;
- Considering the general ineffectiveness of the dewatering equipment on the treated Stratus material, mechanical dewatering is deemed unnecessary and potentially uneconomical at the demonstration and/or full-scale levels;
- No wastewater requiring on-site or off-site management is anticipated from the treatment and/or curing processes at the demonstration and/or full-scale level implementation of the Georemediation™ process. Due to lack of sufficient pore-water generated through mechanical dewatering tests, no pore-water analysis was conducted on the untreated and treated Stratus material during this study.

7.0 CONCLUSIONS

The following section presents the conclusions drawn from the comparison of the results obtained during this pilot study with the success criteria established to achieve the pilot study objectives summarized in Section 4.0.

7.1 Sediment Decontamination Efficacy

Chemical analysis was conducted on the untreated and treated dredged material from both Stratus and Tremley Point locations at bench and pilot scale levels, under various treatment and curing conditions in order to determine the decontamination efficacy of the Georemediation^{TM} technology. The following presents a summary of the conclusions from the chemical analysis results presented in Sections 6.1, 6.2, and 6.3:

- The bulk chemical analytical results for both untreated Stratus and Tremley Point material indicated marginally low levels of selected target contaminants (e.g. PAHs, dioxins, metals), at or below the sediment decontamination efficacy success criteria for "unrestricted" upland use;
- The MEP leachate results for the untreated Stratus material indicate the exceedances of arsenic (As) and lead (Pb) above the NJDEP GWQS during one or more of the seven (7) extraction steps. Therefore, the untreated Stratus material may potentially impact a groundwater source classified as a potable water supply, thereby limiting its upland use in certain applications;
- A total of five (5) Georemediation^{TM} reagent mix types (Mix 1 through Mix 5) were tested for their decontamination efficacy at the bench-scale level for Stratus material. Mix 2 showed the highest overall chemical effectiveness in reducing the total concentration of contaminants of concern in the Stratus material (i.e. PAHs, dioxins). Therefore, Mix 2 was selected for further evaluation at the pilot treatment stage of this study;
- The MEP results of the Stratus material treated using the selected Mix 2 showed significant reductions in the leachability of the metal contaminants. Although, the total metal concentrations in the treated material were below the "unrestricted" upland use criteria (NJDEP RDCSCC), the MEP results still showed the leaching of arsenic (As) and lead (Pb) above the NJDEP GWQS for some of the seven (7) extraction steps;
- The pilot treatment of the Stratus material using Mix 2 at 10% loading was successful in reducing the PAHs contamination below the NJDEP RDCSCC with percent reductions for PAHs observed in the range of 40%-60%. There was no significant reduction in the total metal concentrations, with a general increase in arsenic (As) concentration observed after treatment;
- The pilot treatment results using Mix 2 indicate a general improvement in the percent reduction of organic (PAHs) contaminants over the curing period. A significant improvement in percent reduction was generally observed after a 28-day curing period as compared to a 14-day curing period, with no significant improvement observed thereafter, as determined at the 62-day curing period.

7.1.1 Achievement of Sediment Decontamination Efficacy Success Criteria

Overall, Georemediation^{TM} treatment was unable to achieve the "unrestricted use", sediment decontamination efficacy success criteria, previously established and presented in Table 4-1. However, the pilot study was conducted using Stratus material, which was not considered to be representative of the typical contaminated dredged material anticipated from navigable channels of NY/NJ Harbor due to significant storage in open scows prior to the study, and generally lower than expected types and levels of contaminants. The material treated using Georemediation^{TM} may, however, be beneficially used under certain institutional/engineering controls and restrictions. These restrictions are compatible with the beneficial use markets proposed for the treated sediments.

Table 7-1 re-summarizes the sediment decontamination efficacy success criteria previously presented in Table 4-1, and the results of the pilot study in terms of achieving these criteria.

Table 7-1: Achievement of Sediment Decontamination Efficacy Success Criteria

Beneficial Use Restrictions[a]	Test Parameters	Applicable Success Criteria[b]	Achievement of Success Criteria[b]	
Unrestricted Use	Bulk Sediment Chemistry	RDCSCC	Yes	No
	Dioxins/Furans	TEQ 50 ppt	No	
	Leachate (MEP)	GWQS	No	
Institutional Controls (e.g. Deed Notice)	Bulk Sediment Chemistry	> RDCSCC, NRDCSCC or IGWSCC (as applicable)	Yes	No
	Dioxins/Furans	TEQ 50 ppt	No	
	Leachate (MEP)	GWQS	No	
Institutional/ Engineering Controls (e.g. Deed Notice / Impermeable Cover, etc.)	Bulk Sediment Chemistry	> NRDCSCC or IGWSCC (as appropriate) Site-Specific Criteria	Yes	Yes
	Dioxins/Furans	TEQ > 50 ppt, 1 ppb	Yes	
	Leachate (MEP)	> GWQS, < Site-Specific Criteria	Yes	

[a] Restrictions and success criteria identified are based on NJDEP regulations for upland placement of material in the state of New Jersey (except for dioxins/furans)

[b] RDCSCC: NJDEP Residential Direct Contact soil cleanup criteria; NRDCSCC: NJDEP Non-Residential Direct Contact soil cleanup criteria; IGWSCC: NJDEP Impact to Groundwater soil cleanup criteria; GWQS: NJDEP Groundwater Quality Standards.

7.2 Material Processing and Operational Issues

Decontamination under adverse weather conditions, air emissions sampling and testing, and mechanical dewatering tests were performed on the Stratus material during this pilot study to determine their potential impact on the operational aspects of the Georemediation^{TM} process at the full-scale level. The following presents a summary of the conclusions from these tests:

- The Stratus material treated using Mix 2 at 10% loading at the pilot level and cured at room temperature and humidity conditions showed the highest effectiveness in reducing PAHs contamination as compared to material cured under high relative humidity or freezing temperature conditions. Freezing conditions generally seemed to more severely limit the decontamination of organics as compared to high relative humidity conditions;

- The addition of Georemediation™ Mix 2 in dry form was ineffective in reducing the PAHs concentrations below the NJDEP RDCSCC, as compared to Mix 2 added in a slurried form. Therefore, it is likely that the Georemediation™ reagent will be chemically more effective on organics if used in a slurry form (during treatment) at the full-scale level;
- Stratus material treated and cured at room temperature in deeper curing piles did not show a significant difference in the PAHs reduction as compared to shallower curing pile, with reduction below the NJDEP RDCSCC. This may suggest the possibility of curing the material in deeper piles without compromising on the chemical effectiveness of the Georemediation™ technology and its ability to meet the decontamination efficacy success criteria;
- The target (optimum) moisture content of 36%-39% for the Stratus material treated and cured under room temperature conditions during geotechnical testing, was achieved in 34-43 days. However, during pilot treatment for the chemical analysis, much higher moisture content (56%) was observed even after the 62-day curing period. However, it is anticipated that during field conditions with direct exposure to sunlight and winds, the target moisture content may be achieved in 3-4 week period, previously targeted by BEM for the design of the full-scale facility;
- Two rounds of air emissions testing were performed during the treatment of Stratus material using Mix 2 at 10% loading. The results indicated no emissions for PCBs and metals, with only one Semi-Volatile (SVOC) compound detected;
- Low levels of VOCs were detected during both rounds of air emissions testing, with a general increase in the emissions only after 2-3 days of treatment and curing of the material in open pans. However, the presence of very low levels of VOCs and SVOCs in the untreated Stratus material indicate that no major facility air permit (Title V) or the implementation of the State-of-the-Art (SOTA) technology for emissions controls is anticipated to be required. However, further air emissions testing must be performed on a representative and freshly dredged material with higher levels of contamination to corroborate these conclusions. A minor facility air permit will be required at the full-scale level, as more than fifty (50) pounds of raw material per hour is anticipated to be processed at the full-scale level.
- The results of the mechanical dewatering tests using belt filter press technology indicated that untreated Stratus material could be dewatered from 45% solids upto 57% solids under normal operating conditions. However, the Stratus material treated with Mix 2 at 10% loading could only be dewatered from 45% solids to 49% solids;
- The treated material passed the paint filter test immediately after treatment, thereby indicating no potential leachate generation during the curing of the material. Therefore, no contaminated wastewater requiring on-site or off-site treatment is anticipated to be generated during the treatment and curing of the material;
- The dewatering of the contaminated dredged material prior to or after the Georemediation™ treatment is not recommended at the full-scale level due to inherent need for moisture to support decontamination reactions, general ineffectiveness of the mechanical dewatering equipment, and ability of the treated material to withhold any free water.

7.2.1 Achievement of Material Processing and Operational Success Criteria

Since BEM's pilot study was conducted on a laboratory scale with limited material, space, and resources, further testing at a larger scale may be necessary to evaluate all potential material processing and operational aspects of the full-scale treatment. However, this pilot study was designed to get a preliminary understanding of some of the important material processing and operational issues anticipated at the full-scale level. The following sub-sections discuss the achievement of the success criteria established in Section 4.2.2 based on the results of this study.

7.2.1.1 Air Emissions Control Requirements

Since more than fifty (50) pounds of raw material per hour will be processed at the full-scale level, a minor facility air permit will be required for the implementation of the Georemediation^{TM} technology. In addition, based on the characterization, and air emissions testing results during treatment and curing of the Stratus material, no major facility permit (Title V) and/or implementation of the SOTA technology is anticipated. However, the Stratus material provided for this pilot study was not considered to be representative of the contaminated material likely requiring decontamination after dredging from the navigable channels of the NY/NJ Harbor and prior to upland placement. This is because of extended storage (7 months) of the Stratus material in open scows, subsequent re-hydration and re-homogenization, prior to its use in the pilot study. Therefore, further air emissions testing may be required to determine the need for a major facility (Title V) permit or the implementation of a SOTA technology during the full-scale implementation of the Georemediation^{TM} technology.

7.2.1.2 Decontamination Under Adverse Weather Conditions

The Stratus material treated during the pilot stage was cured under the following adverse weather conditions to determine their impact on the chemical effectiveness of the Georemediation^{TM} treatment:

- High Relative Humidity (R.H. > 95%);
- Freezing Conditions (Temperature 32° F).

In general, the highest percent reductions in the contaminants of concern (i.e. PAHs, dioxins/furans) in the Stratus material, were observed during the curing of the material at room temperature (RT). The achievement of the sediment decontamination efficacy success criteria under these conditions is previously discussed in Section 7.1.1. The curing of the treated material under adverse weather conditions was unable to meet the success criteria previously established in Section 4.2.2 due to the following reasons:

- Non-compliance of the end-product with the "unrestricted" beneficial use criteria;
- Greater than 20% RPD between the results under the adverse weather conditions and the most chemically effective conditions observed (RT), thereby suggesting a negative impact of the adverse weather conditions.

As previously discussed, although the material treated under the adverse weather conditions did not meet the "unrestricted" use criteria, the treated material may be beneficially used in certain applications with appropriate institutional and/or engineering controls and restrictions.

7.2.1.3 Depth of Curing Piles

In general, greater than +20% RPD was observed between the results under the most chemically effective conditions (RT), and the average results under the deeper pile curing conditions, thereby suggesting a positive impact of the deeper curing piles. However, the curing of the treated material at room temperature under deeper curing piles was unable to meet the sediment decontamination efficacy success criteria previously established in Section 4.2.2 due to the following reason:

- Non-compliance of the end-product with the "unrestricted" beneficial use criteria.

7.2.1.4 Mechanical Dewatering/Wastewater Treatment Requirements

Although, detailed economic analysis is beyond the scope of this pilot report, BEM's past experience and prior knowledge indicates that the use of mechanical dewatering equipment before or after the Georemediation^{TM} treatment will be more costly than the open curing. This assumption is also based on the results of this pilot study which indicate a general ineffectiveness of the mechanical dewatering equipment to significantly reduce the moisture content of the treated material. The mechanical dewatering of the untreated or Georemediation^{TM} treated material is not recommended due to the following observations;

- Inherent moisture of the untreated material will likely improve the chemical effectiveness of the Georemediation^{TM} treatment of organics;
- The Georemediation^{TM} treated material passes the Paint Filter Test, thereby indicating absence of any free liquid that may require appropriate management.

Therefore, Georemediation^{TM} technology is considered to have achieved the success criteria established for the evaluation of mechanical dewatering equipment.

Table 7-2 summarizes the material processing and operational success criteria previously discussed in Section 4.2.2., and the results of the pilot study in terms of achieving these criteria.

Table 7-2: Achievement of Material Processing and Operational Success Criteria

Test Conditions	Test Parameter	Applicable Success Criteria	Achievement of Success Criteria	
Air Emissions Control Requirements	Major Facility (Title V) Permit	Emissions < Major Facility Threshold	Yes	Yes
	SOTA Technology Implementation	Emissions < SOTA Threshold	Yes	
Adverse Weather Conditions (High Relative Humidity)	Impact on Chemical Efficacy (Organics)	RPD < |20|% (Compared to Results under Room Conditions)	No	No
	Increase in Curing Period to Achieve Target Moisture Content	Curing Period: 34-43 Days (Based on Results under Room Conditions)	No	
Adverse Weather Conditions (Freezing Conditions)	Impact on Chemical Efficacy (Organics)	RPD < |20|% (Compared to Results under Room Conditions)	No	No
	Increase in Curing Period to Achieve Target Moisture Content	Curing Period: 34-43 Days (Based on Results under Room Conditions)	No	

Test Conditions	Test Parameter	Applicable Success Criteria	Achievement of Success Criteria	
Deeper Curing Piles	Impact on Chemical Efficacy (Organics)	RPD > 20% (Compared to Results under Room Conditions)	Yes[a]	Yes
	Increase in Curing Period to Achieve Target Moisture Content	Curing Period: 34-43 Days (Based on Results under Room Conditions)	Yes[b]	
Mechanical Dewatering/ Wastewater Treatment Requirement	Operational Viability	Not Required of Economically Viable	Yes	Yes
	Wastewater Treatment	Not Generated or Treatment/Disposal Economically Viable	Yes	

[a] Deeper curing piles appear to generally improve the reduction of PAHs contaminants. However, further testing is necessary to corroborate these conclusions

b Although, the deeper curing pile slightly delayed the achievement of target moisture content under laboratory conditions, it is anticipated that target values will be achieved during normal field conditions

7.3 Anticipated Beneficial Reuse Applications

Geotechnical laboratory testing was conducted on Stratus material treated with Georemediation^{TM} Mix 1 and Mix 2 added in a slurry form, and Mix 2 added in a dry form, at 10% loading rate, to evaluate their geotechnical suitability for the anticipated beneficial use applications listed in Section 4.2. The following presents a summary of the conclusions from the geotechnical test results presented in Section 6.4.:

- The untreated Stratus material and all treated materials classified as elastic silt (MH) under the Unified Classification system;
- The moisture–density relationships for all the treated materials indicate a range from 60 to 80 pcf in dry density (90% Modified Proctor) with corresponding water contents ranging from 60% to 40%, respectively. Stratus material treated with Mix 1 was the lightest due to its fluffy and compressive nature, with the unit weight increasing to 80 pcf for material treated with Mix 2 [DRY]. Typical values for amended dredge material (8% Portland Cement) from previous works conducted at the Rutgers/CAIT facility are 60 pcf for dry density and 49% water content, respectively;
- The CBR values ranged from 1 to 3 for Stratus material treated with Mix 1 and Mix 2 [DRY], respectively. These values were for samples tested at 90% Modified compaction effort. The CBR values increased with compaction effort but nevertheless remained low for potential base and sub-base applications. These values correspond to typical CBR values for MH soils, which range in value from 4 to 8;
- Resilient modulus measures the strength of sub-grade soils under dynamic vehicular loads. The resilient modulus of Stratus material treated with Mix 2 [DRY] compared well with three sub-grade soils that are currently used in the construction of New Jersey roadways;
- The unconfined compressive strength of the Stratus material treated with Mix 1 and Mix 2 [RT] were 70% lower than the material treated with Mix 2 [DRY]. The strength values were in the range for stiff to very stiff clays. Mix 2 [DRY] can be considered for potential fill

applications but shear strength parameters need to be determined prior to stability of analysis of slopes per specific project;

- None of the treated materials tested showed any potential to collapse under the particular compaction and loading characteristics tested in the study. In fact, the first two loading schemes for the Stratus material treated with Mix 2 [DRY] actually caused a slight swelling effect; therefore, negative % collapse was shown. This also provides evidence of the higher swelling potential exhibited earlier in the swell potential tests. This reflects favorably on the potential use of the treated material for the construction of embankments or dikes;
- The swell potential for all treated materials tested were relatively low compared to data from Holtz and Kovacs, 1981. The swell potential for the Stratus material treated with Mix 2 [DRY] was higher than the material treated with Mix 1 and Mix 2 [RT], when water was introduced to the compacted material;
- The permeability values ranged from 7×10^{-7} to 1.6×10^{-6} for the Stratus material treated with Mix 2 [DRY] and Mix 2 [RT], respectively. The data showed that the material could be considered for landfill cap or liner applications;
- Stratus material treated with Mix 2 [DRY] failed the freeze-thaw susceptibility test and thus would require proper coverage in potential field applications, or further amendments to make it suitable for such applications.

7.3.1 Achievement of Beneficial Use Success Criteria

The achievement of the beneficial use success criteria varied based on the type of beneficial use application. The following summarizes the results based on the anticipated beneficial use applications and success criteria previously presented in Section 4.2.3:

7.3.1.1 Transportation and Infrastructure Construction Projects

In general, Stratus material treated with Mix 2 [DRY] was found to be more suitable for construction fill applications where higher shear strength was required under service loads. These applications could be used as construction fill to support both static and dynamic loads. As with the use of material treated with Mix 1 and Mix 2 [RT], based on the wet-dry tests, proper soil cover would need to be provided at all times to minimize strength loss and erosion. Furthermore, compacting the treated Stratus material at moisture contents below the shrinkage limit would minimize the potential for tensile cracks and thereby minimize any further strength loss in the material. Therefore, the Goremediation™ treated Stratus material could potentially be successfully used in several transportation and infrastructure construction project applications, with appropriate design modifications. However, it is recommended that the geotechnical testing of the treated material continue to evaluate the performance of the material in a field pilot program to better understand and assess the beneficial reuse potential of the material. The additional testing must also include the evaluation of amendment materials to further reduce .

7.3.1.2 Brownfields Remediation and Reclamation Projects

Although, there are no existing standards or criteria relating to the bearing capacity for the reuse of dredged material as general backfill, Georemediation™ treated material may be used for certain fill application for the brownfields remediation and reclamation projects. Stratus material treated with Georemediation™ mixes showed permeability values acceptable for potential liner or cap applications when properly designed.

7.3.1.3 Landfill Cover

As per the guidelines provided in the October 1997 NJDEP Technical Manual, NJDEP will evaluate the suitability of the dredged material proposed for landfill cover on a case-by-case basis.

The use of the Georemediation™ treated sediments for daily or intermediate landfill cover may be limited due to strict grain-size requirements and concerns related to its susceptibility to wind blown dust, erosion, and potentially limiting hydraulic conductivity. The Georemediation™ treatment with Mix 1 reduced the fraction of material passing No. 200 sieve from 29% to approximately 18%, which is below the 20% requirement for daily or intermediate landfill cover. Although, a general reduction in the fine-grained fraction was observed for material treated with Mix 2, achievement of grain-size requirements may largely depend upon the grain-size analysis of the untreated source material.

However, the use of Georemdiation™ treated material for final landfill cover may be more appropriate due to permeability values less than 1 x 10^{-5} cm/sec observed after treatment. In addition, the general improvements in the strength characteristics and workability of the material make it more suitable for use as final landfill cover material.

Table 7-3 summarizes the beneficial use success criteria previously discussed in Section 4.2.3 for the proposed beneficial use applications, and the results of the pilot study in terms of achieving these criteria.

Table 7-3: Achievement of the Beneficial Use Success Criteria

Beneficial Use Application	Test Parameter	Applicable Success Criteria (Performance Based)[a]	Achievement of Success Criteria	
Transportation and Infrastructure Construction Projects	Bearing Strength Characteristics	CBR: 10-20	No	Yes[c]
		Resilient Modulus: 6,000 – 10,000	Yes	
	Compaction Characteristics	Maximum Dry Density (MDD) > 76 lb/ft^3	Yes	
	Deformation Characteristics	Swelling < 4%	Yes	
		Collapse Potential	Yes	
		Free Thaw Index: 2 - 5	Yes	
Brownfields Remediation and Reclamation Projects	Bearing Strength Characteristics	Unconfined Compressive Strength: Variable	No	Yes[c]
	Permeability Characteristics	Permeability < 10^{-7}	Yes	
Landfill Cover Projects	Grain Size Analysis	Fraction Passing No. 200 < 20% (Daily or Intermediate Cover)	Yes[b]	Yes[c]
	Bearing Strength Characteristics	Unconfined Compressive Strength: Variable	No	
	Permeability Characteristics	Permeability < 1 x 10^{-5} (Final Cover)	Yes	

[a] Performance based success criteria are assumed based on the actual use of typical material for sub-grade structural fill applications for NJDOT projects

[b] The grain size requirements for the daily or intermediate landfill cover may be met based on the source material characteristics

[c] Further amendments of the material may be necessary in certain applications to achieve the overall success criteria (e.g. amendments to further improve bearing strength, freeze/thaw susceptibility, etc.)

8.0 SCALE-UP POTENTIAL, ECONOMIC PROJECTION, AND MARKET ANALYSIS

The ultimate goal of OMR's sediment decontamination technologies development program is to evaluate the chemical and geotechnical efficacy, as well as economic viability of the decontamination technologies for their application to the dredged material from the NY/NJ Harbor at the full-scale level.

As per the information provided on OMR's website, OMR hopes to achieve this goal through fostering the startup of businesses that can provide cost-effective sediment decontamination on a commercial scale (up to 500,000 cubic yards annually per facility). OMR believes that the economies of scale and relatively constant supply of feedstock available in the navigational dredging program should enable these businesses to capitalize equipment and keep costs down. In the short-term, OMR hopes to have at least 2 fully functional commercial-scale decontamination (enterprises) businesses in the harbor by 2003, with an aggregate capacity of at least 1,000,000 cubic yards of sediment management annually, at a cost to the dredger of no more than $29 per cubic yard delivered. The cost of $29 per cubic yard includes any potential revenues generated from the beneficial use of the decontaminated end-product. OMR hopes that eventually, one or more of the businesses will be able to treat more highly contaminated sediments from off-channel locations such as Passaic River, NJ and the Gowanus Canal, NY, which are likely contributing contaminants to the harbor and its sediments, and limiting development in the region.

The objective of the OMR's sediment decontamination pilot program was for the decontamination vendors to evaluate and address as many issues as possible to determine the commercial viability of their respective technologies. The following sections discuss the scale-up potential, economic, and commercial viability of the Georemediation^{TM} technology for its application to the NY/NJ Harbor sediments, based on the results of this pilot study conducted by BEM at the Rutgers Laboratories.

8.1 Scale-Up Potential

The Georemediation^{TM} process involves the mixing of a proprietary reagent in a slurry form with the dredged material, followed by curing in open piles for a required period of time, prior to transfer for beneficial use. A more detailed overview of the Georemediation^{TM} decontamination mechanisms and the process was previously provided in Section 3.0. BEM considers the process as "low-tech", capable of utilizing mostly off-the-shelf equipment as compared to other sediment decontamination technologies currently under development. The actual Georemediation^{TM} process may be very well compared with the typical solidification/stabilization (S/S) processes currently being used successfully for the amendment of the dredged material from the NY/NJ Harbor for upland beneficial use, with the added benefit of actually degrading organic contaminants to innocuous by-products.

In May 1998, in response to OMR's RFP designed to seek out innovative and commercially viable decontamination technologies, BEM demonstrated the scale-up potential of the Goremediation^{TM} process through detailed design and economic analysis, the technology achieved the chemical and geotechnical effectiveness for the proposed beneficial use applications. As part of this RFP response, BEM performed the analysis for commercial scale implementation (i.e. management of 500,000 CY to 1,000,000 CY of sediments annually) as well as demonstration scale projects (i.e. 20,000 CY to 130,000 CY of sediments).

BEM based the above analyses on the following strategy to establish scale-up potential of the Goremediation™ process from pilot- and demonstration-scale upto the full-scale level:

- Flexibility in facility operation;
- Utilization of proven material handling and processing technologies;
- Utilization of readily available off-the-shelf equipment;
- Use of modularized designs and process trains;
- Minimization of waste generation and worker safety risks.

Table 8-1 re-summarizes the site requirements previously used for BEM's documentation of the scale-up potential of the Georemediation™ technology at both demonstration and full-scale levels.

Table 8-1: Initial Site Requirements for Georemediation™ Scale-Up

Minimum Requirements	Demonstration Project (30,000 to 150,000 cys)	Full-Scale Project (500,000 cys)
Plot Area	6-8 Acres	15-20 Acres
Minimum Dock Length	100'	250'
Water Treatment	0.5MGD	0.5MGD
Barge Delivery	2,000-3,000 cys/day	2,000-3,000 cys/day
Transportation Mode	Truck and Rail	Truck, Rail, and Barge
On-site Storage[a]	7 days	14 days

[a] On-site storage refers to the storage capacity for the untreated material received at 2,000 – 3,000 cys/day prior to its treatment

Although, the site requirements listed above will generally remain the same, the process and facility unit operations, and the facility design basis for both the demonstration and full-scale levels will need to be modified based on the results of this pilot study.

Since, BEM's pilot study was conducted at a laboratory scale using limited amount of dredged material (total approximately 600 gallons), the study was designed to further evaluate the following issues that were likely to impact the facility operations and design basis:

- Need for air emissions control technologies (e.g. SOTA technologies);
- Need for mechanical dewatering prior to or immediately after the treatment of the dredged material;
- Need for wastewater collection from the treatment and/or curing stages, and on-site/off-site treatment of the wastewater;
- Need for shallower curing piles thereby requiring larger plot space for the curing of the treated end-product.

Although, BEM collected useful data during this pilot study, the dredged material provided by OMR for this study is not considered as representative due to extended storage (over 7 months) of the material in open scows. The extended storage may have resulted in substantial changes to both the physical and chemical characteristics of the material that would be typically received for treatment at the full-scale level. In addition, the material was generally found to be lacking of the several target contaminants above levels requiring decontamination prior to upland beneficial use. However, the results of this pilot study reflect favorably on the previously documented scale-up potential of the Georemediation™ technology. Specifically, the following conclusions either meet the design parameters or eliminate certain operational processes initially incorporated into BEM's analysis:

- The levels of VOC emissions detected during air emissions testing were too low to warrant implementation of air emissions control technologies or procurement of a major facility (Title V) permit. However, these results are strictly based on the material provided for this study and may not represent the results anticipated for contaminated material received at the full-scale level;
- Mechanical dewatering of the untreated (raw) dredged material was not recommended prior to treatment due to general ineffectiveness of the dewatering equipment, and inherent benefit of the moisture in aiding the Georemediation™ decontamination mechanisms;
- Mechanical dewatering of the treated dredged material was not recommended due to the ability of the Georemediation™ reagent to absorb any free water, thereby suggesting no need for the collection of wastewater immediately after treatment and/or curing processes. In addition, mechanical dewatering tests were unsuccessful in significantly reducing the moisture of the treated sediments;
- No wastewater treatment is likely required during or after treatment, unless the wastewater is generated at the source due to significantly higher water content of the material dredged and transported to the treatment facility;
- A comparison of the PAHs results for the treated Stratus material do not suggest any negative impact of the deeper curing piles on the chemical effectiveness of the Georemediation™ technology. Therefore, deeper piles requiring smaller plot area may be viable during the full-scale treatment. However, the deeper piles will delay the achievement of the optimum moisture content for beneficial use, thereby potentially requiring longer curing periods than desired. However, further testing will need to be conducted at the field scale level to corroborate these results.

wouldn't VOCs be low because of storage?

Table 8-2 provides a summary of the process and facility unit operations previously used to demonstrate scale-up potential, and potential modifications based on the pilot study results discussed above.

Table 8-2: Proposed Modifications to the Process & Facility Operations for Georemediation™ Scale-Up

Unit Operation	Proposed Modifications (Based on Pilot Study Results)
Sediment Preparation & Transfer	None
Reagent Storage	None
Sediment Treatment	None
Sediment Curing and Drying	No mechanical dewatering required; No leachate collection system required; Deeper curing piles may reduce plot area requirements.

? isn't this counter to results ↑As? ↑Pb?

Unit Operation	Proposed Modifications (Based on Pilot Study Results)
Sediment Processing and Transfer	None
Wastewater Treatment	Not Required ?
Air Emissions Controls	Not Required ?
Support Facilities	None

these are contrary to concs. regarding extended storage

Apart from the proposed modifications listed above, BEM does not anticipate any major changes to the design basis and assumptions previously used for the economic analysis of the Georemediation™ scale-up. The following re-summarizes some of the key design basis and assumptions previously used:

- All Facilities including sewers available at the property fence line;
- Dock Facilities Size: ± 500 L.F.; based on?
- Years of Facility Operation (Minimum): 10 Years;
- Capital Investments Amortization (With Zero Salvage Value): 3 Years;
- Equipment on Stream Factor (Operating Period): 10 Months;
- Facility Throughput/Treatment Rate: 3,000 cys/day; [not high enough, need storage]
- Number of Shifts: 7 days/week for 10 months/year;
- Sediments Specifications (Percent Solids): 30% to 50%;
- Stockpile Availability On-Site: 30,000 cys of Treated Material;
- Percent Loading of Georemediation™ Reagent: 10% to 15%; → based on this lousy sample? what if hotter?
- Disposal of off-spec material (debris) as follows: 0.5% by Weight (Maximum). [not realistic]

8.2 Economic Projection

A detailed economic analysis of the full-scale implementation of the Georemdiation™ technology, as presented in BEM's response to OMR's RFP in May 1998, documented the potential net cost for the treatment at $33.74 per cubic yard. In August 1999, as part of selected vendors presentations prior to contract award, BEM presented the following strategies to further reduce the treatment cost to under $29 per cubic yard, as re-established by OMR:

- 30 Year Amortization instead of 10 Year (for equipment, infrastructure, and facility upgrades);
- Exclude the cost of transportation of the treated end-product to the end users; why?
- Exclude the potential cost of host facility fees; why?
- Exclude the cost of land credit (e.g., property lease for the first year).

Table 8-3 presents a summary of the economic feasibility study of the Georemediation™ scale-up, based on the initial assumptions presented in May 1998, and a revised economic projection based on the above assumptions (except for a 20 year amortization instead of 30 years), and the proposed modifications based on the results of this pilot study.

Table 8-3: Revisions to the Economic Feasibility Study for Georemediation™ Scale-Up

Cost Item	Previous Cost Projection		Revised Cost Projection	
	Total Cost ($/Yr)	**Unit Cost ($/CY)**	**Total Cost ($/Yr)**	**Unit Cost ($/CY)**
Dredging	**$0**	**$0**	**0**	**0**
Fixed Direct Cost				
Process Equipment	$7,542,330	$1.51	$6,796,330[a]	$0.68[d]
Infrastructure	$14,291,918	$2.86	$12,937,471[b]	$1.29[d]
Engineering/Permitting	$2,393,681	$0.96	$2,224,352[c]	$0.88
Host Facility Upgrade	$1,782,886	$0.36	$1,782,886	$0.18[d]
Subtotal	$26,010,815	$5.68	$23,741,039	$3.03
Contingency	$1,950,811	$0.43	$1,950,811	$0.43
Escalation	N/A	N/A	N/A	N/A
Subtotal	**$27,961,626**	**$6.11**	**$25,691,850**	**$3.46**
Operating Expense				
Labor	$1,915,732	$3.83	$1,915,732	$3.83
Rolling Stock	$106,700	$0.21	$106,700	$0.21
Shop/Office Supplies	$27,200	$0.06	$27,200	$0.06
Utilities	$379,200	$0.76	$379,200	$0.76
Process Chemicals	$150,000	$0.30	$150,000	$0.30
Misc. Engineering Support	$880,000	$1.76	$880,000	$1.76
QA/QC Testing	$200,000	$0.40	$200,000	$0.40
Transportation	$1,000,000	$2.00	$0	$0.00
Subtotal	**$4,658,832**	**$9.32**	**$4,658,832**	**$7.32**
Georemediation™ Reagent (10% Loading)	**$5,750,000**	**$11.50**	**$6,500,000**	**$13.00[e]**
Commercial Expenses				
Property Lease (1 Yr)	$300,000	$0.60	$0	$0.00
Financing Cost (5 Yrs Total)	$2,500,000	$2.00	$2,500,000	$2.00
Facility Insurance (1 Yr)	$100,000	$0.20	$100,000	$0.20
Advertising & PR (1 Yr)	$100,000	$0.20	$100,000	$0.20
Professional Services (1 Yr)	$50,000	$0.10	$50,000	$0.10
Taxes (1 Yr)	$110,000	$0.22	$110,000	$0.22
Subtotal	**$5,660,000**	**$3.32**	**$5,360,000**	**$2.72**
Host Facility Payments	**$500,000**	**$1.00**	**$0**	**$0.00**
Profit				
Processing Fee @ Front End	**$1,250,000**	**$2.50**	**$1,250,000**	**$2.50**
Product Resale @ Back End	**$0**	**$0**	**$0**	**$0**
TOTAL COST	**$45,780,458**	**$33.74**	**$42,960,682**	**$29.00**

[a] Cost revised to exclude equipment cost related to wastewater treatment

[b] Cost revised to exclude Infrastructure costs for the wastewater treatment and support facilities cost for wastewater sewer

[c] Cost revised to exclude engineering and permitting costs related to wastewater treatment

[d] Unit costs revised based on 20 year amortization instead of 10 years

[e] Unit cost for Georemediation™ reagent is revised based on the assumption that more expensive ingredients may be required to improve upon the chemical and geotechnical effectiveness achieved during this study, in order to meet the success criteria

The above economic analysis is based on the assumption that the Georemediation^{TM} treated end-product will be offered to the user at no material cost ($0). However, typical material costs for Zone III, embankment fill material used for structural and non-structural applications range from $4 to $6 per cubic yard in northern New Jersey. This may provide significant incentive to the Contractors in accepting this alternative material, since the NJDOT contract awards are generally based on lowest bid. Any additional incentives derived from the sale of the treated end-product will only further improve the economic viability of the full-scale Georemdiation^{TM} treatment facility.

The above cost revisions for the decontamination and beneficial use of the NY/NJ Harbor dredged material at a the full-scale level (i.e. 500,000 CY sediments annually) using Georemediation^{TM} technology at $29 per cubic yard, also assumes the following:

- The most optimum Georemediation^{TM} reagent and percent loading rate required to achieve the desired chemical effectiveness for the proposed beneficial use applications will be designed under the revised economics of $13 per cubic yard of sediments treated;
- The treated end-product will be geotechnically suitable for the anticipated beneficial use applications;
- There will be a significant market for the anticipated beneficial use applications to accommodate all of the treated material on an annual basis.

no different than current pozzolano

Therefore, further testing of the chemical effectiveness of the Georemediation^{TM} technology is recommended with a more contaminated and representative material, in order to further develop an effective reagent mix design and accurately determine the economics of the reagent material.

8.3 Beneficial Use Market Analysis

The results of the geotechnical testing, presented in Section 6.5, indicate that the material treated with Georemediation^{TM} technology may be suitable for anticipated beneficial use applications. However, in some applications, further improvement of the material or design modifications may be required to allow the proposed beneficial use of the material. The geotechnical suitability of the treated material, as discussed in Section 6.5, does not taken into consideration the compliance of the material with the regulatory cleanup criteria applicable to each beneficial use application. However, the contaminant levels achieved after treatment during this study are deemed acceptable for the proposed beneficial use applications, except for certain potential engineering and/or institutional control restrictions in some cases.

As previously summarized in Section 4.2, BEM proposes to use the Georemediation^{TM} treated end-product as structural and/or non-structural fill in the following beneficial use applications and projects:

- Transportation and Infrastructure Construction Projects;
- Brownfields Remediation and Reclamation Projects;
- Landfill Cover.

BEM believes that it is critical that the beneficial use of the treated sediments not be limited to one type of market or customer base. Therefore, additional beneficial use applications may be explored in the future. However, the perceived stigma of the dredged material or "NIMBY" (not in my back yard) concerns, regulatory process to determine acceptable use, or typical market forces may at any time halt or delay the beneficial use of the material. Therefore, the potential for material stockpiling or "backing up" at the treatment facility is probably one of the main issues confronting the long-term commercial viability of a high volume sediment decontamination program.

However, BEM believes that the beneficial use markets identified above have the combined potential to satisfy the market need for treated dredged material, provided certain technical, regulatory, and political advances are made at the local and state level to further develop these markets. The following subsections presents BEM's knowledge of the beneficial use markets for the proposed beneficial use applications, and steps being taken to further at the local, state and private sector level to further improve upon the acceptability of the treated sedimdents.

8.3.1 Transportation and Infrastructure Construction Projects

As presented in the 1996 Joint Dredging Plan between the New York and New Jersey, the NJDOT was mandated by the Governor to find beneficial use of upto 700,000 CY of sediments on an annual basis in state transportation and infrastructure construction projects.

Since 1996, BEM's research and knowledge show that there is considerable potential demand for structural and non-structural fill in transportation and infrastructure construction projects initiated by NJDOT, New Jersey Transit (NJT), New Jersey Transportation Planning Authority (NJTPA), and Port Authority of New York/New Jersey (PA of NY/NJ). As part of the federal Transportation Equity Act for the 21st Century (TEA-21), New Jersey has developed a multimodal Statewide Transportation Improvement Program (STIP) for all areas of the state. NJDOT has developed an estimate of $7.4 billion in available state and federal revenues to support the state's transportation budget during the three fiscal years from FY02 through FY04. NJDOT expects this amount to be available under a multi-year funding process for the FY02-FY04 Statewide Transportation Improvement Program.

In FY02 alone, approximately $1.07 billion will be used to support the Transportation Capital Program initiated by NJDOT and NJT, which include improvements planned for local and state highway needs, rail and bus improvements, airports, public transit projects, and transportation and economic development projects. As part of the proposed Transportation Capital Program, New Jersey has also submitted a "Draft Five-Year Capital Plan" from FY02 through FY06, and a "Draft State Long-Range Plan, Choices 2025" to the legislature to establish overall policy and strategic direction for transportation in New Jersey.

Based on the information provided in the 2001 Bid Price Report, prepared by NJDOT, Cost Estimating Division, the following provides a summary of the total construction fill quantities (converted to English units), and the average total unit cost, including the material, transportation, and placement, for all NJDOT projects in year 2000:

Zone 1 Material: 3,049 cubic yards ($13.38/cubic yard);

Zone 2 Material: 28,086 cubic yards ($8.71/cubic yard);

Zone 3 Material: 211,759 cubic yards ($12.11/cubic yard);

Borrow Excavation/Bridge Foundation Material: 21,817 cubic yards ($23.28/cubic yard).

The Georemediation^{TM} treated dredged material may only be potentially used for Zone 3 embankment fill (structural and non-structural) or borrow excavation material for placement around bridge foundations (structural). Although, BEM was unable to obtain quantities from other years, BEM believes that transportation and infrastructure market may be the single most important potential market for long-term and sustainable beneficial use of the decontaminated dredged material from NY/NJ Harbor. A review of the proposed improvements for FY02 under the Transportation Capital Program indicates a number of projects that may require significant amounts of structural and non-structural fill, throughout the state of New Jersey.

In order to further develop this beneficial use option, and make the treated dredged material generally acceptable to the construction contractors and the governing agencies such as NJDOT, a better understanding of the geotechnical performance of the treated dredged material will be required. To this end, OMR, under NJDOT, and through Rutgers University, CAIT institute, has recently completed a geotechnical report for the "OENJ/NJOT Roadway Embankment Pilot Project" in Elizabeth, New Jersey. This pilot project was designed to study the feasibility of beneficially reusing Stabilized Dredged Material (SDM) in the construction of road embankments. The results of this study are quite encouraging and indicate that SDM may be potentially used as structural and non-structural fill applications in transportation projects, with minimal design restriction and/or modifications. The study also recommends conducting additional demonstration projects to test the beneficial use of the SDM under dynamic loads. The results of such efforts may eventually be used by NJDOT to develop performance-based standards and criteria for the beneficial use of the amended dredged material in transportation and infrastructure construction applications.

however there are sign. issues Contam & freeze thaw

8.3.2 Brownfields Remediation and Reclamation Projects

The brownfields reclamation and redevelopment is a burgeoning potential beneficial use market, especially in the State of New Jersey. Several brownfields redevelopment projects involving the beneficial use of SDM have been successfully completed in the recent past, including OENJ Orion Mall project in Elizabeth, New Jersey. With the passing of the "Brownfield and Contaminated Site Remediation Act" in 1998, subsequent formation of a "Brownfields Redevelopment Task Force", and the adoption of an "Action Plan in 2000, it is clear that New Jersey is committed to spur the redevelopment of brownfields sites in the state.

One of the most relevant brownfields development program, initiated by North Jersey Transportation Planning Authority (NJTPA) and the New Jersey Institute of Technology (NJIT) is currently in its second phase to explore the opportunities for freight-related redevelopment of abandoned industrial brownfield sites in the NY/NJ region. The project is funded under the federal Transportation and Community and System Preservation Pilot (TCSP) program. As part of this program, NJTPA has identified more than 450 acres of recommended brownfield sites, which can be readily developed as distribution centers, adjoining container yards, and linked dedicated freight-ways along the NY/NJ Harbor. The proposed brownfields redevelopment as part of this program provides excellent opportunity to incorporate the benefits of using the treated dredged material for the reclamation of these sites, especially for the sites in close proximity to the waterfront.

BEM has worked with NJTPA and NJIT in providing consulting services as part of this redevelopment program to evaluate, document and determine target brownfields sites. As part of this contract, BEM has provided the following services to NJTPA:

- Development of brownfields site database for thirteen counties;

- Brownfields site screening;
- Identification and selection of sites with high potential for freight-related redevelopment;
- Transportation Asset Assessment;
- Delineation of environmental sensitive areas;
- Fiscal benefits through empowerment zones;
- Social benefits.

Based on BEM's experience and working knowledge, BEM is confident that Georemediation™ treated end-product can serve as a cost-effective means to meet the requirements for the site capping and fill material for brownfields reclamation projects.

8.3.3 Landfill Cover

The suitable physical characteristics of the Goremediation™ treated dredged material for daily and/or intermediate cover, and strength and permeability characteristics for final cover for sanitary landfills provide additional opportunities for its beneficial use.

As state in NJDEP's guidance document for "The Management and Regulation of Dredging Activities and Dredged Material in New Jersey's Tidal Waters" (Technical Manual), the need for landfill cover across New Jersey is substantial. Currently, 25 landfills remain in operation in New Jersey. Fourteen of these facilities are large county-wide or regional landfills, which utilize substantial quantities of daily, intermediate, and final cover. The balance consists of 9 small sole source construction and demolition debris or company landfills, and 2 very small municipal landfills. In addition, NJDEP has identified a total of 578 sites, which may require final closure and remediation.

Based on the information provided in the Annual Landfill Topographic Reports prepared by NJDEP, Division of Solid and Hazardous Waste (DSHW), the following approximately quantities of daily/intermediate cover and final cover were collectively placed in approximately 22 sanitary landfills in the State of New Jersey from 1998-2000:

- 1998: Daily or Intermediate Cover: 1,500,000 cubic yards; Final Cover: 218,000 cubic yards;
- 1999: Daily or Intermediate Cover: 950,000 cubic yards; Final Cover: 0 cubic yards;
- 2000: Daily or Intermediate Cover: 1,450,000 cubic yards; Final Cover: 325,000 cubic yards.

Although, the final cover quantities appear to vary more significantly, the landfill cover applications provide significant opportunities for the beneficial use of treated dredged material.

9.0 RECOMMENDATIONS FOR FURTHER STUDY

Based on the results of this pilot study presented in Section 6.0, Georemediation^{TM} technology was unsuccessful in meeting or exceeding all of the success criteria established by BEM to demonstrate its chemical and geotechnical effectiveness for all the proposed beneficial use applications. However, Georemediation^{TM} technology showed favorable results for the treatment of certain contaminants (e.g. PAHs) and the geotechnical performance of the end-product for some of the beneficial use applications. But further testing and studies will be required to address issues not adequately covered during this pilot study, especially the need for representative and contaminated material from the navigable channels of the NY/NJ Harbor.

The following presents a summary of BEM's recommendations towards achieving the proposed pilot study objectives:

Sediment Decontamination Efficacy

- Use of more heavily contaminated and freshly dredged material from the navigable channels of NY/NJ Harbor, with organic and metal contaminant concentrations exceeding the NJDEP RDCSCC. The use of more heavily contaminated material will provide BEM with an opportunity to evaluate the effectiveness of Georemediation^{TM} on a complex contaminated material. In addition, high levels of contaminants will provided BEM with measurable, statistically significant impact on the concentration of contaminants after treatment, thereby helping in the optimization and development of the Georemediation^{TM} treatment conditions;
- Field curing of the treated material at a larger scale in order to determine the potential curing period required at the full-scale level to achieve the desired moisture content for the proposed beneficial use;
- Use of multiple extractions for representative samples to ensure complete recovery of organic contaminants (including dioxins) prior to the instrument analysis by the analytical laboratory. This recommendation may provide better insight into the actual changes in the contaminant concentrations after treatment, especially at low levels, and provide means for a more reliable contaminant mass balance.

yet none was done

Material Processing and Operational Issues

- Implementation of the Georemediation^{TM} process at a larger scale to further evaluate its material handling, operational success under varying weather conditions, and economic viability;
- More elaborate air emission testing, including contaminant mass balance, to determine the total contaminant air emissions loadings and requirements for air emissions control.

Anticipated Beneficial Use Applications

- An evaluation of various amendment materials to further improve the geotechnical performance of the Georemediation^{TM} treated end-product for the proposed beneficial use applications;
- An evaluation of economic impact of additional amendments to the Georemediation^{TM} treated end-product;
- Investigation and evaluation of additional beneficial use applications.

Economic Projection and Market Analysis

- Revisions to the economic projections based on the results of future tests and studies;
- Investigation of actual quantities of fill material required for the proposed beneficial use applications in the state of New Jersey for the foreseeable future;
- Investigation of the advances in the technical and regulatory fronts to facilitate the beneficial use of the amended dredged material for the proposed and/or additional upland beneficial use applications.

10.0 REFERENCES

- Ali Maher, Ph.D., Soiltek, Inc., "Final Geotechnical Report – OENJ/NJDOT Roadway Embankment Pilot Project at Parcel G of the OENJ Redevelopment Site, Elizabeth, Union County, New Jersey", Prepared for New Jersey Office of Maritime Resources (OMR), New Jersey Department of Transportation (NJDOT), Sadat Associates, Inc., and OENJ Corp., March 2001;
- BEM Systems, Inc. (BEM), "Proposal for Sediment Decontamination Demonstration Project: Bid No. 98-X-99999", submitted to Department of Commerce and Economic Development, May 1998;
- BEM, "Quality Assurance Project Plan (QAPP), Pilot Study – Georemediation™ Technology", 31 May 2001;
- BEM, "Health And Safety Plan (HASP), Pilot Study – Georemediation™ Technology", 31 May 2001;
- John A. Apps, Ph.D., "Rapid Destruction of Hazardous Organic Wastes in Sol without Emissions", Prepared for Jeffery Newton, Aleph Group, April 1999;
- New Jersey Department of Environmental Protection (NJDEP), "The Management and Regulations of Dredging Activities and Dredged Material in New Jersey's Tidal Waters" (Technical Manual), October 1997;
- NJDEP, Division of Solid and Hazardous Waste (DSHW) "Solid Waste Regulations, N.J.A.C. 7:26, Subchapter 2A. Additional Specific Disposal Regulations for Sanitary Landfills", July 2001;
- NJDEP, DSHW, " Annual Landfill Topographic Reports", 1998-2000;
- New Jersey Department of Transportation (NJDOT), "Transportation Capital Program – Fiscal Year 2002", July 2001;
- NJDOT, "New Jersey Statewide Transportation Improvement Program (NJ STIP) – Fiscal Years 2002-2004", October 2001;
- NJDOT, Division of Cost Estimating, "Bid Price Report for Standard Pay Items, January to December, 2000", 2001.