FHWA-NJ-2005-014

# Geotechnical Testing and Beneficial Reuse Evaluation of River Sediments Palmyra Cove Demonstration Project

FINAL REPORT
June 2005

Submitted by

Dr. Ali Maher
Professor and Department Chair

Center for Advanced Infrastructure & Transportation (CAIT)
Civil & Environmental Engineering
Rutgers, The State University
Piscataway, NJ 08854-8014

NJDOT Research Project Manager
Mr. Scott Douglas

In cooperation with

State of New Jersey
Department of Transportation
Office of Maritime Resources
and
U.S. Department of Transportation
Federal Highway Administration

# Disclaimer Statement

TECHNICAL REPORT STANDARD TITLE PAGE

| | | |
|---|---|---|
| 1. Report No.<br>FHWA-NJ-2005-014 | 2. Government Accession No. | 3. Recipient's Catalog No. |
| 4. Title and Subtitle<br>Geotechnical Testing and Beneficial Reuse Evaluation of River Sediments<br>Palmyra Cove Demonstration Project | | 5. Report Date<br>June 2005<br>6. Performing Organization Code<br>CAIT/Rutgers |
| 7. Author(s) Dr. Ali Maher | | 8. Performing Organization Report No.<br>FHWA-NJ-2005-014 |
| 9. Performing Organization Name and Address<br>State of New Jersey<br>Department of Transportation<br>PO Box 607<br>Trenton, NJ 08625-0607 | | 10. Work Unit No.<br>11. Contract or Grant No. |
| 12. Sponsoring Agency Name and Address<br>Federal Highway Administration<br>U.S. Department of Transportation<br>Washington, D.C. | | 13. Type of Report and Period Covered<br>Final Report<br>01/1/2002 - 6/20/2005<br>14. Sponsoring Agency Code |
| 15. Supplementary Notes | | |

16. Abstract

The objective of the work was to provide NJDOT with useful information in order to pursue beneficial use of dredged sediments. This study focused on the geotechnical properties of materials; other studies conducted concurrently considered ceramic uses and environmental characteristics of the materials. This study used common field and laboratory investigation methods to evaluate the dredged material for potential future roadway, embankment, and waste containment applications. The results are compared to those of more common materials, and published standards, where existing, used in these applications.

| 17. Key Words | 18. Distribution Statement |
|---|---|
| Dredged Sediments, Roadway Aggregate, Embankment Materials, Beneficial Use | |

| 19. Security Classif (of this report) | 20. Security Classif. (of this page) | 21. No of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 49 | |

**Form DOT F 1700.7** (8-69)

## TABLE OF CONTENTS



## Appendices

## TABLES



## FIGURES

## Executive Summary


Findings of a study conducted by the Center for Advanced Infrastructure and Transportation (CAIT) at Rutgers University on geotechnical and environmental characteristics of sediment previously dredged from the Delaware River are presented in this report. The study also includes assessment of potential application of the dredged material in road and other construction projects.

Sediment dredged hydraulically from the Delaware River has been historically placed in numerous diked areas along the NJ and PA shorelines where the water passively drains back to the river through a weir system. These structures are known as confined disposal facilities (CDF) and have been widely used by the US Corps of Engineers and the State of NJ in their respective dredging programs for decades. Unfortunately, these structures have a finite capacity and new locations to construct CDFs in shoreline areas are becoming more and more difficult to locate, obtain and permit. The NJ Department of Transportation is currently exploring the potential for the dried sediment in the CDFs to be used beneficially for construction projects throughout the State. If uses for the material can be found, the existing CDFs could be emptied and made available for continued use. In order to determine whether or not this is technically, environmentally, and economically feasible, data on the physical and chemical characteristics are needed. This study specifically evaluated material in a single CDF.

Approximately 450,000 cubic yards of dredged sediments are currently stored in a confined disposal facility (CDF) at Palmyra Cove, New Jersey. Twenty (20) samples were collected from eight (8) locations and transferred to Rutgers University's geotechnical laboratory for identification and strength tests. Environmental testing including priority pollutant organics and metals were also performed to determine any potential limitations to applications that would result from the presence of unacceptable concentrations of these chemicals in the dredged material.

The dredged material at the Palmyra Cove CDF can be mostly classified as silty sand (SM), poorly graded sand with silt (SP-SM) and poorly graded sand (SP) according to the Unified Soil Classification System. Most of the material conforms to NJDOT Zone III embankment material criteria and NJDOT I-11, I-12 and I-13 aggregate standards. Hydraulic conductivity (permeability) of compacted samples ranged from $6.24 \times 10^{-5}$ to $1.87 \times 10^{-2}$ cm/sec. with an average of $5.97 \times 10^{-3}$ cm/sec. Material of this type provides fair drainage for applications such as road sub-base or fills behind retaining wall or reinforced slopes.

Strength tests including triaxial shear, California Bearing Ratio (CBR) and Resilient Modulus (Mr) were performed to determine the dredged material's friction angle (Ø) and cohesion intercept (c) as well as strength under dynamic (vehicular) loading. The friction angle ranged

from 36 to 39 degrees with the average of 37.7 degrees. The average cohesion intercept was 1.7 psi. Based on these values, in the absence of surcharge and groundwater pressures, an embankment constructed of compacted dredged sand with side slope of 3.6 horizontal to 1 vertical would have a factor of safety of at least 1.5.

The average CBR value was 26 indicating that the dredged sandy material is well within the range of values considered to be a fair sub-base and a good sub-grade material. CBR values of sub-base material in the 20 to 30 range are common for current roadway projects. Resilient modulus of the dredged sand was in the range of 6,525 psi to 11,353 psi with the average of 8,600 psi, which compares favorably the typical New Jersey sub-grade soils used for sub-base applications.

Other applications in addition to common fill, backfill behind retaining walls, embankment fill, sub-base and sub-grade material, could be drainage layer in sanitary landfills if the material is mixed with low percentages of gravel size aggregate or crushed glass. Blending the dredged sand with gravel will enhance the engineering properties such that it could conform to other NJDOT aggregate standards.

The material was tested for the presence of chemical contamination using standard NJDEP protocols for dredged material. According to the chemical test results, the dredged material meets the NJDEP Residential Direct Contact Soil Cleanup Criteria. The NJDEP currently allows wide unregulated use of dredged material that meets these chemical criteria.

Currently NJDOT approved material for various transportation applications costs anywhere from $5 to $10 per cubic yard. Cost for stockpiling, loading, transportation, placement and compaction should be added to overall fill material cost. As for dredged sand, the cost for all above elements remains the same while Palmyra Cove dredged sand costs approximately $3.5 (Robert Shinn, 2003). Utilization of dredged sand therefore will be economically feasible compared to other NJDOT standard materials as long as the destination site is within a reasonable distance from Palmyra Cove. Otherwise, material supplied from local sources is less costly. For each specific application and destination, an analysis is needed to ensure there will be cost saving by using the dredged sand.

Other parameters affecting the overall cost of utilizing dredged sand in confined disposal facilities currently (CDF) existing along Delaware river such as access in and out of the CDF, traffic restricts on trucks in the vicinity of the CDFs, access roads within the CDF, proximity to currently active construction sites in need for fill material, grubbing and cleaning requirements prior to excavation and loading, the overall volume of material stored in each CDF and how the material is distributed over each site.

## Introduction

This report presents the findings of a study to evaluate the geotechnical aspects of potential beneficial use of dredged sediments from the Delaware River at Palmyra Cove, New Jersey. The sediments evaluated are currently stockpiled on land adjacent to the river at Palmyra Cove. Over a number of years, these sediments were hydraulically removed from the adjacent section of the river to deepen shipping channels. Due to the length of time these sediments have been in their current upland location, some of the sediments now support trees while most show only short weeds. Based on the nature of the material, it has been believed that the sediments have the potential for a variety of uses and some market value associated with possible uses. In 2002, the work plan was approved that authorized the work contained in this study.

As directed by the New Jersey Department of Transportation (NJDOT) Office of Maritime Resources, this study focused on three potential beneficial use options for the dredged sediments: embankments, sub-grade fill, and sub-base aggregate. Some consideration was also given to the materials for waste containment applications. A sampling and testing program was developed to evaluate the suitability of the dredged sediments for the potential applications by comparing geotechnical properties with those of other soil materials typically used in such applications.
We understand that currently crushed glass is stockpiled at Burlington County's Waste Management Facility. Blending of crushed glass with dredged sand as mentioned earlier, will enhance some engineering properties of the mix. While the mixing adds to the overall cost, the mixed material will have a potentially higher market value that supercedes the mixing cost.

### 1.0 Fundamentals of Evaluating Engineering Behavior of Soils

Soil behavior for engineering purposes is best evaluated though a variety of tests. To best predict behavior in future field conditions, the testing should include measurement of the intended soil properties for a potential application. Tests such as three-dimensional strength, permeability, response to one-dimensional stress, are often used to model the conditions a soil material may experience. However, since soils cannot be considered for every potential application and condition, index properties are used by geotechnical engineers to predict behavior based on empirical data and to verify the general accuracy of direct testing. Due to the body of empirical data collected over the last century, the relative effectiveness of soil materials in certain applications can be estimated through the soil's index properties.

Simple testing for index properties permits classification of soil materials among similar soils and estimating the properties of concern without actually measuring them directly. The engineering behavior of soils is a function of a variety of factors including: the size and shape of the soil particles, the mineralogy of the fine-grained particles, the density of the particles, the stress history of a soil, and the water content of a soil mass. These and other properties are not themselves typically properties that can be directly related to stability in potential applications but properties we can relate to the behavior under the conditions of concern.

A proper testing program should both classify the soils with respect to their index properties, and to the extent possible, measure their intended properties directly through tests that simulate the states and conditions under which the properties will be exhibited. For a study such as this one in which soils are in a location and state different from their eventual application(s), both types of tests are important in evaluating future applications.

## 2.0 Study Methods

The study methods included four components:

- Sampling
- Laboratory testing
- Data Evaluation
- Application Evaluation

Each of these is discussed in detail below:

## 2.1 Sampling

### 2.1.1 Determination of Sample Locations and Depths

Based on consultation with NJDEP's Office of Dredging and Sediment Technology, a total of eight sample locations were identified. These sample locations were selected using NJDOT's computer program for random sample location selection. The program is a Microsoft Excel-based program primarily used for testing pavement sections of roadways. To use the program, the irregularly-shaped area containing the sediments, totaling approximately 70 acres, had to be divided into areas approximating rectangles. To best create the rectangles, the site was divided into a total of eight areas. The eight sub-areas ranged in area from approximately 8 to 10 acres each. The sample locations selected by the computer program are shown on Figure 1.

The sampling was performed by Rutgers University Department of Civil and Environmental Engineering (RU CEE) and Stevens Institute of Technology (SIT) on March 27, 2002 with assistance from ACT Engineers Inc. (ACT) and the earthwork contractor retained at the Palmyra Cove site. The total depth of the sediments varies across the 70 acres. Where the dredged sediments at the sample location exceeded a total thickness of five feet, three samples were taken at different depths; where the depth of sediments was less than five feet, two depth intervals were sampled. The intent of this depth strategy was to collect samples representative of the material


**Figure 1: Site Plan Showing Sample Locations**

present, identifying total depths, where possible. Additionally, if stratifications were present, such stratification could be observed, sampled, and documented.

Table 1 below summarizes the location-depth strategy used to collect representative samples:

| | **Table 1. Study Test Pit Sample Depth Scheme** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Depth** | **1** | **2** | **3*** | **4** | **5** | **6** | **7** | **8** |
| **Surface** | X | X | | X | X | X | X | X |
| **3-5’** | X | X | | X | X | X | X | X |
| **5-10’** | X | X | | X | | X | X | X |

X = a sample was collected and retained from this depth interval
*Although samples were collected from STP-3, they were not tested as part of this study because they contained construction debris. No dredged sediments were present based on visual examination.

### 2.1.2 Sample Collection

With the assistance of the on-site contractor and ACT, eight study test pits (STP-1 through STP-8) were excavated using a backhoe at the selected sample locations (Figure 1). Prior to beginning excavation, surface vegetation was scraped away from the test pit location. Test pits were excavated with sloping sufficient to minimize sloughing of sediments from the sidewalls into sampling zones below. Excavation and labor activities were conducted in accordance with applicable OSHA requirements.

Visual and textual observations were noted at each location and depth. No obvious stratifications were seen in the test pits, except where the material changed from dredged sediments to native materials. Geotechnical testing samples were collected by removing material at the specified depth from the backhoe bucket with a shovel or trowel and placing it into clean plastic bins (20-gallon capacity). The bins were then sealed and labeled. The labels indicated the date and time of the sampling, the sample location, and the depth of collection. Samples were then transferred to RU's truck for transportation to the RU CEE testing laboratory. Between sample locations, the backhoe bucket, shovels and trowels used at the last location were pressure-washed with water to reduce the potential for influencing material from one sample location to another.

After completing the sampling, the exploratory test pits were backfilled with the sediments excavated from each location and the ground surface was restored to its approximate previous elevation.

## 3.0 Laboratory Testing

In accordance with the approved work plan, the samples were tested in two stages. The first stage focused on the primary index test relevant to potential transportation applications. The second stage focused on tests simulating the conditions under which the engineering properties of concern will be exhibited.

## 3.1 Stage I Testing

The first stage consisted of primarily visual and textual classification tests to permit classification based on Unified Soil Classification System (USCS) (ASTM Standard D498) and the New Jersey Department of Transportation (NJDOT) standards for gradation of fine and coarse aggregates. Specifically, the testing included in-situ water content determination, grain size distribution, and determination of specific gravity of solids. Our laboratory technician attempted to perform testing for Atterberg limits (liquid and plastic limits); however after including a very large volume of bulk sample, fine fraction of particles (silt and clay size) were not sufficiently plastic to perform the liquid and plastic limit testing. In accordance with the Unified Soil Classification System, Atterberg limit results for soil samples with less than 12% silt and clay do not affect the soil's classification.

Copies of the generalized Unified Soil Classification System Chart and NJDOT criteria for standard aggregate are included in Appendix A.

### 3.2 Stage II Testing

The Stage II testing subjected the material to conditions potentially simulating actual transportation applications using standard test methods. Every re-use option involves excavation of the sediments, transportation, moisture conditioning and compaction (as appropriate for the application). Thus, the sampling program focused on the properties of the material in a compacted condition.

These performance-based tests included permeability, California Bearing Ratio (CBR), Resilient Modulus ($M_R$) and triaxial shear strength of samples prepared under laboratory compaction conditions similar to probable field density and moisture states. A summary of the test methods, their applicable standards, and their purpose is presented in Table 2.

**Table 2. Test Methods Summary**

| Test Name or Parameter | Applicable Standard | Purpose/Comment |
|---|---|---|
| Particle-size analyses | ASTM D421/422 | UCSC & NJDOT size criteria |
| Specific gravity of solids | ASTM D854 | Characterizes solids present |
| Percent moisture | ASTM D2216 | Typical water content in field |
| Atterberg Limits (LL,PL,PI) | ASTM D4318 | Assess property changes due to moisture change |
| Hydraulic Conductivity (rigid wall) | ASTM D 5856 | Permeability under compacted conditions |
| Hydraulic Conductivity (flexible wall) | ASTM D 5084 | Permeability under compacted conditions with 3-D confining stress |
| California Bearing Ratio (CBR) | ASTM D 1883 | Traditional standard for road section design |
| Resilient Modulus | AASHTO T 274-82 | Simulation of performance under traffic loads |
| Compaction Test (Standard Proctor) | ASTM D 698 | Moisture-density relationship under simulated field compacted conditions |
| Triaxial Shear Strength (Consolidated Undrained) | ASTM D4767 | Strength/stability in embankment and slope applications |

### 3.3 Sample Preparation

Sample preparation for the geotechnical testing of the dredged materials changed moisture (or water) content, and density for samples for some of the tests as appropriate. When modified, the density was changed through the use of laboratory compaction using standard methods discussed below. The following table indicates the state the soils were tested in, and modifications:

**Table 3. Summary of Sample Preparation Methods**

| Test Name or Parameter | Purpose/Comment | Conditions of sample(s) |
|---|---|---|
| Particle-size analyses | UCSC & NJDOT size criteria | Dried |
| Specific gravity of solids | Mineral content/volume-density relationships | Test takes small portion of grains |
| Percent moisture | Typical water content in field | As sampled |
| Atterberg Limits (LL,PL,PI) | Assess property changes due to moisture change | Water added |
| Hydraulic Conductivity | Permeability under compacted conditions | Saturated, compacted to 90% of maximum dry density based on laboratory compaction test |
| California Bearing Ratio (CBR) | Traditional standard for road section design | Compacted to 95% of maximum dry density, moisture conditioned to within 3% of optimum moisture content |
| Resilient Modulus | Simulation of performance under traffic loads | Compacted to 95% of maximum dry density, moisture conditioned to within 3% of optimum moisture content |
| Compaction Test (Standard Proctor) | Moisture-density relationship under simulated field compacted conditions in the laboratory to determine maximum dry density | Water added to varying percentages of moisture by dry weight, this test increases soil density and permits evaluating the variation in maximum density with changing water content |
| Triaxial Shear Strength (Consolidated -Undrained) | Strength in embankment and slope applications | Compacted to 95% of maximum dry density, moisture conditioned to within 3% of optimum moisture content. The soil is then saturated for testing. |

## 4.0 Results

### 4.1 Geotechnical Stage I Test Results

*Grain Size Distribution and Specific Gravity*

Grain-size distribution of soils can be evaluated in a variety of ways. A sandy or gravelly soil is considered to be well graded if it includes a variety of particle sizes that are relatively evenly distributed. The letter "W" as the second letter of a soil classification under the unified soil classification system refers to well-graded. A soil is considered to be poorly-graded if it is limited to a narrow range of particle sizes; the term "P" as the second term of the unified classification system refers to a poorly-graded soil. A soil that is predominantly two sizes is referred to as gap-graded and is usually classified as well graded with respect to the USCS. A primary method of quantitatively evaluating the grading of soils is through comparing the $D_{60}$, $D_{30}$, and $D_{10}$ grain sizes (the particle size in mm or inches corresponding to the percentile of the soil by weight smaller than that size). Thus $D_{10}$ is the size (in inches or mm) corresponding to the $10^{th}$ percentile for a soil sample.

The coefficient of uniformity, Cu, is defined as $C_u = \frac{D_{60}}{D_{10}}$

The coefficient of curvature (or variation) Cc, is defined as $Cc = \frac{D^2{}_{30}}{D_{10}D_{60}}$

Soils with a Cu greater than 6 and a Cc between 1 and 3 are classified as a well –graded sand (SW). Soils with Cu less than 6 and Cc less than 1 or greater than 3 are defined as poorly graded sand (SP).

Based on the test results, the dredged materials are considered silty sands and poorly-graded sands (SM and SP classifications) based upon the USCS. The samples contained as little as 0.4% fines (silt- and clay-sized sediments) to as much as 35.8 % fines. The Cu ranged between 2.18 and 3.98. The Cc ranged between 0.8 and 1.66.

The relative proportions of silt and clay are typically not tested since the effort to perform such tests are often not of as much value as performing other tests that more directly evaluate the property of concern (permeability, expansiveness, etc.) Laboratory testing confirmed the field observations that there was no consistent correlation between the percentage of fines and depth. However, certain areas of the Site may have received sediments containing varying amounts of fines relative to other areas. Since different areas of the river channels were dredged at different times and different sizes of particles are deposited during different depositional conditions, some variation in particles distribution was expected. The specific gravity of the sediments clustered around an average 2.67, indicating a predominance of quartz minerals. The specific gravity of quartz is about 2.65. A summary of grain size distribution and specific gravity results is presented on the attached Table 4.

## 4.2 Geotechnical Stage II Test Results

*Laboratory Compaction*

Since the material in its anticipated applications will be compacted to a standard degree of compaction (typically 90 or 95% of the maximum dry density based on laboratory compaction), the first test performed was laboratory compaction. The test defines maximum dry density for a particular soil under a standard compaction method. The defined property is dry density rather than total density in order to consider the soil solids only and not let the density be temporarily or artificially changed due to changes in moisture in the soil pore spaces. Laboratory compaction testing permits one to approximate the conditions that will result on a site when soils are properly moisture conditioned and compacted using large equipment. The soil density provides an important index property to predict other properties such as bearing capacity, Resilient modulus-value, shear strength, and hydraulic conductivity that may result when a soil is properly compacted in an earth fill.

Laboratory compaction testing was performed in accordance with the Standard Proctor Method (ASTM D698) on samples from each of the depth intervals (15 samples total). The maximum dry density ranged from 90 to 114 pounds per cubic foot (pcf), averaging 101 pcf (all dry density). The optimum moisture (water) content ranged from 11 to 19 percent (%) water by weight. The average optimum moisture content was 16.9%. The conversion between dry density and wet (bulk) density is $\gamma_w = \gamma_d(1+w)$ where $\gamma_w$= the wet density, $\gamma_d$ = the dry density and w= the water content (on a mass basis in decimal form). The attached Table 5 presents a summary of the compaction testing results.

*Permeability Testing*

Permeability (also known as hydraulic conductivity) testing was performed to evaluate the material's ability to drain water or to dissipate pore water pressure. This property is critical for the long-term performance of embankments and pavement sections. It is also a critical property for evaluation of performance in solid waste containment applications. A number of test methods are used to determine soil hydraulic conductivity. Two primary laboratory methods are rigid wall and flexible wall testing. The rigid wall method (ASTM D 5856) tests the flow of water though saturated soils compacted in a rigid wall mold unit, known as a permeameter. The flexible-wall method (ASTM D5084) uses a flexible rubber membrane sealed against the sides of a cylindrical sample. Both methods use Darcy's law of flow though porous media, determining only one-dimensional permeability. Compacted samples were used for the flexible wall test method. For the purposes of this study, based on the grain size distribution, we assumed that the material is isotropic with similar permeability in every direction. Thus one-dimensional permeability is a representative test. For predominantly granular materials, this assumption is typical and appropriate.

In general, the flexible wall method is recommended for soils with hydraulic conductivities less than 1 x $10^{-3}$ cm/sec ASTM). Since the range of permeability values found is near this value, results from both rigid wall and flexible wall tests are considered of value.

As shown in Table 6, the hydraulic conductivity of compacted samples ranged from 6.24 x$10^{-5}$ cm/sec to 1.87 x $10^{-2}$ cm/sec.

The permeability of a soil is directly related to the grain size; thus a fine-grained soil will have a significantly lower permeability than a course grained soil. As a rough index of permeability, the percentage of fine-grained particles (those in the silt and clay fraction, passing the #200 sieve) is used, since the grain size is directly proportional to permeability. The $D_{10}$ grain size (the size representing the $10^{th}$ percentile of sizes in a soil) is sometimes used as a semi-quantitative empirical correlation of permeability. The permeability is related to the grain size distribution in Table 7. For the samples tested in this study, the permeability generally increases with grain size. However the relationship is not always liner; as discussed above, specific testing is a more accurate determination than using index properties.

*Shear Strength Testing*

Soil strength behavior is best modeled using the Mohr-Coulomb Failure Criterion. The primary equation for this relationship is:

$S = C' + \sigma' \tan Ø$

Where:

S = the soil's shear strength for a specific confining stress condition
C' = the soil effective cohesion value (in units of pressure)
σ = the normal effective stress at that location, and
Ø = the soil's internal angle of friction

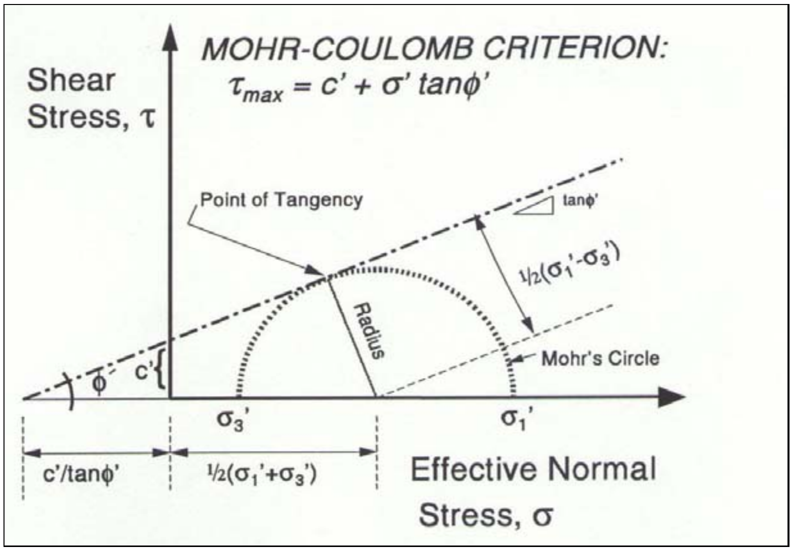



**FIGURE 2: Mohr-Coulomb Strength Envelope**

Shear strength is largely a function of normal stress for soils (except for clays in saturated, undrained conditions). The relationship between normal stress and maximum shear strength approximates a straight line for typical conditions. We develop this relationship through a series of tests where the points of tangency are determined. The lines connecting of points of tangency (usually extrapolated and interpolated based on a few points) is referred to as the failure envelope. The failure envelope represents the critical combination of shear and normal stresses where failure develops for a particular soil.

Laboratory shear strength testing of soils is most accurately determined by triaxial testing, which simulates three-dimensional stress conditions that may develop in-situ.

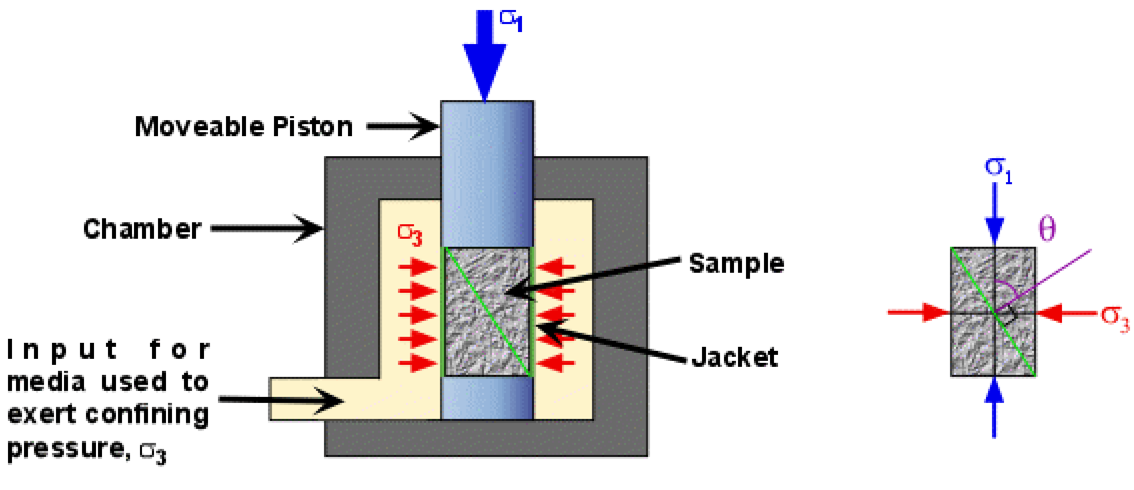



**FIGURE 3: Triaxial Testing Diagram**

Triaxial testing was performed in accordance with the Consolidated-Undrained method on samples compacted to between 94 and 100 percent maximum dry density as per the Standard Proctor Method (ASTM D698). Tests were performed at confining pressures ($\sigma_3$) of 5, 10, and 15 pounds per square inch (psi) (The equivalent values in SI units are 34.5, 69, and 103.4 kN/m$^2$). A total of 15 samples were tested using this method.

*California Bearing Ratio (CBR)*

In accordance with ASTM D1883, a total of 15 laboratory-compacted soil samples were tested for California Bearing Ratio (CBR). The test is commonly used for design of flexible pavement's sub-grade, sub-base, and base course. Laboratory compacted samples are used for testing. The CBR test advances a piston into the compacted sample and determines the stress required to advance the piston 0.1 in (2.54 cm) and 0.2 in (5.08 cm) into the sample. Typically, the bearing ratio reported is the one associated with the 0.1 in (2.54 cm) penetration.

The results indicated that the statistical average value was 26.1. The highest value obtained was 52.4 and the lowest value was 18.3. The Standard deviation for the results was 9.23. These results are summarized in Table 9.

*Resilient Modulus*

Resilient modulus ($M_r$) provides a dynamic evaluation of the performance of potential sub-base materials that is more representative of the actual impact loading conditions that a pavement section may experience during it's design life. The samples tested in this study were compacted between 95 to 100% of their respective maximum dry density. Resilient modulus testing was conducted in accordance with AASHTO designation TP46-94 for sub-grade soils of a sample diameter of 2.8 inches.

Since the $M_r$ is a stress dependent parameter, it is not possible to assign one resilient modulus value to any given soil. Therefore, the resilient modulus values used for comparison are for the pavement section/stress condition depicted in Figure 4. For comparison purposes, the typical pavement section (Figure 4) was developed and analyzed using elastic layered theory to determine the bulk stress and deviatoric (the difference between the maximum, or bulk, and minimum normal stresses) stress due to an 18 kip applied axle load. The results were the following:

Bulk Stress = 9.1 psi

Confining Stress = 5.0 psi

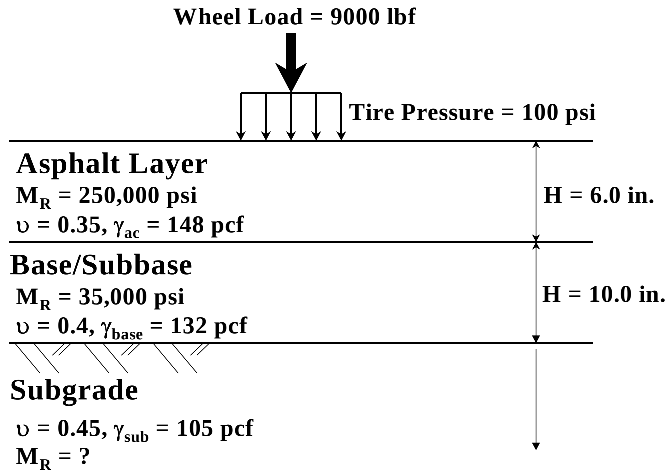



**Figure 4 – Typical Pavement Section for Resilient Modulus Determination**

## 5.0 Discussion of Results

*Grain Size Distribution*

The Palmyra Cove dredged material is generally classified as poorly graded sand (SP), silty sand (SM) or sand with silt (SP-SM). Based on these results, much of the dredged material conforms to NJDOT Zone III embankment material criteria. Additionally, most of the material conforms to NJDOT, I-11, I-12, and I-13 NJ aggregate standards. Conformance with a variety of specific standards is discussed in detail below.

*Hydraulic Conductivity*

The permeability of the dredged material corroborates to dense silty sand or, well graded clean sand (Freeze and Cherry, 1979). Thus, the potential applications once slightly modified include roadway embankment layers and solid waste containment system drainage layers. This material should not be considered for potential landfill liner or cap applications.

As shown in Table 6, the hydraulic conductivity of compacted samples ranged from 6.24 x$10^{-5}$ cm/sec to 1.87 x $10^{-2}$ cm/sec.

*Triaxial Shear Testing*

The triaxial testing results indicate that the material has favorable shear strength properties, typical of sand-silt mixtures. The consistency of the strength behavior makes this material a good material for design purposes due to its predictability. There are no applicable standards for friction angle and cohesion values, however determination of these values are necessary when calculating Factor of Safety (FS) for embankments or bearing capacity of foundations for structures supported by this material.

The results indicated very consistent values for the strength parameters Ø and C. The mean friction value was 38 degrees with standard deviation of 1.7degrees. The mean cohesion value was 1.67 psi (240 psf or 11.5kN/$m^2$). The standard deviation of the cohesion intercept was 0.69. A summary of the triaxial testing results is presented in Table 8.

*California Bearing Ratio (CBR)*

With an average CBR value of 26.1, the results indicate that this material is well within or above the range of values considered to be a fair sub-base and a good sub-grade material. That range is typically taken to be values in the 7 to 20 range (AASHTO). Since only three of the test results (20%) were below 20, the results show that the material should perform well as a sub-base or sub-grade. CBR values of sub-base material in the 20 to 30 range are common for transportation projects. It is our opinion that the material is a fair to good sub-base material.

*Resilient Modulus*

Figure 3 summarizes the Resilient Modulus test results and compares the results with two soils, A-2-4 and A-3, representative of typical New Jersey sub-grade soils. As can be seen from Figure 3, the STP soils compare favorably to the typical New Jersey sub-grade soils when analyzed using the stress regime shown in Figure 2. In fact, the STP soils typically show a greater resilient modulus than the typical New Jersey sub-grade soils.

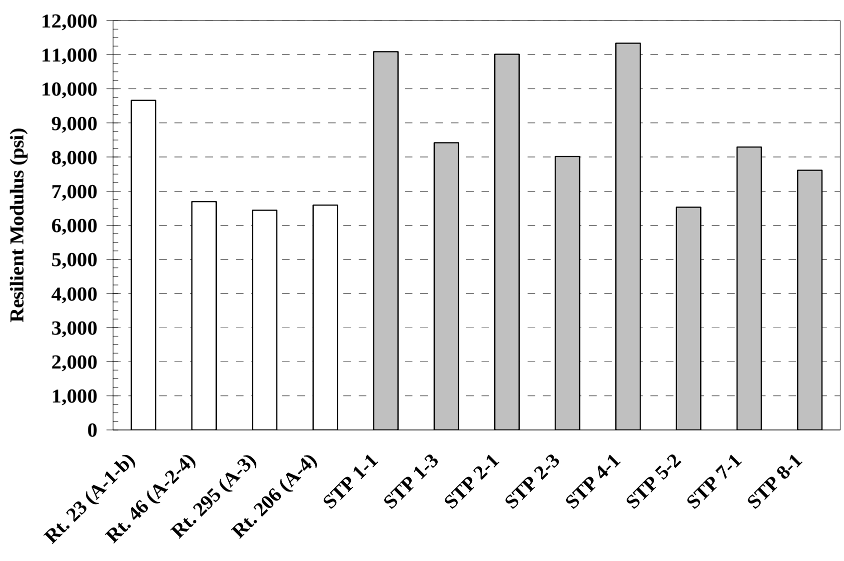



**Figure 5: Resilient Modulus Test Results for Palmyra and Other NJ Sub-grade Materials**

Based on the pavement section/stresses depicted in Figure 2, the average resilient modulus for all samples tested was 8,600 psi. The largest value was found for STP 4-1 (11,353 psi), and the lowest value was found for STP 5-2 (6,525 psi). Figure 5 shows the values for the samples tested, along with resilient modulus values for typical sub-grade soils found in New Jersey.

### 5.1 Engineering Options and Environmental Issues

The engineering applications for this material considered as part of this study among others included road base and embankment. The results of this study indicate that the material will perform satisfactorily in these applications. The dredged sediments perform favorably when compared to similar materials used in these applications that are quarried in New Jersey. It is our opinion that these materials may have other applications as well, including building materials, such as mortar blocks, geosynthetic covers, landfill drainage layers, and pipe trench backfill, and fill behind retaining walls or mechanically stabilized walls. Some of these applications such as landfill drainage layer would require the blending of the dredged sediments with other materials.

### 5.2 NJDOT Standard Soil Aggregate Gradation

The gradations of the collected samples were compared to “NJDOT Standard Specifications, Division 900 Materials, Section 901- Aggregates” gradation designation for the following application:

1. Aggregate For Bituminous Concrete, Section 901.10-C
2. Aggregate For Portland Cement Concrete, Mortar, and Grout , Section 901.13-B
3. Mineral Filler, Section 901.15
4. Standard Soil Aggregate Gradations, Table 901-2
5. Borrow Excavation, Section 204.02

The gradation of the samples collected at the site was compared to gradation designations for the above applications as well as NJDOT Standard Soil Aggregate Designation, Table 901-2, I-1 to I-13 designations. While the samples tested did not conform to the designations for Borrow Excavation, Mineral Filler, aggregate for Portland Cement Concrete, Mortar and Grout, they all did conform to specifications for Aggregate for Bituminous Concrete, Zone 3 Embankment fill as well as a few Standard Soil Aggregate Gradations designations (Table 901-2) as presented in Table 10.

Blending the material with predetermined percentages of coarse sand and gravel can make it suitable for a wide range of NJDOT applications. A summary of other applications is presented in Table 10.

**Table 10**

| Sample | Conforming to I-1 to I-13 Designations |
|---|---|
| STP 1-1 | I-11, I-13 |
| STP 1-2 | I-13 |
| STP 1-3 | None |
| STP 2-1 | None |
| STP 2-2 | I-11, I-12, I-13 |
| STP 2-3 | I-13 |
| STP 3-1 | None |
| STP 4-1 | I-3, I-11, I-12, I-13 |
| STP 5-1 | I-11, I-12, I-13 |
| STP 5-2 | I-11, I-13 |
| STP 6-1 | I-11, I-12, I-13 |
| STP 6-3 | I-11, I-12, I-13 |
| STP 7-1 | I-11, I-12, I-13 |
| STP 7-2 | I-11, I-12, I-13 |
| STP 8-1 | None |

*CRUSHED GLASS*

At the request of the Burlington County Resource Recovery Complex (BCRRC), the Rutgers University Department of Civil and Environmental Engineering (CEE) performed grain size distribution tests on samples of crushed glass and sand provided. The testing was performed in accordance with standard ASTM D421.

Test results indicated that the sand provided was typical of a poorly-graded sand (SP) material based on Unified Soil Classification System (UCSC) standards. The glass was a well-graded sand (SW) based on UCSC standards.

Blending of crushed glass with the Palmyra sediments or sand can be successfully achieved for use in non-structural applications for drainage layers

## 5.3 Applications in Sanitary Landfills

Soil aggregate suitable for landfill drainage layers, grading material to support buildings on landfills, and bedding and cover material for membranes are outlined in the NJDEP's Solid Waste Regulations, N.J.A.C. 7:26, Subchapter 2A. For each application, specifications are presented and a determination has been made whether or not the tested samples meet those specifications.

The material used in drainage layer, aggregate for supporting buildings constructed over landfills according to N.J.A.C. 7:26, Subchapter 2A shall be an open graded material or clean aggregate. The material shall meet the following criteria of the cumulative grain size distribution curves:

1) $D_{85}$>4$D_{15}$ and
2) $D_2$> 0.1 inch (2.5 mm)

Where $D_{85}$, $D_{15}$ and $D_2$ are the diameters corresponding to the 85%, 15% and 2% finer respectively for a soil sample.
Among the samples tested, none had $D_2$ larger than 0.1 inch and therefore do not qualify for drainage layer or aggregate supporting buildings. However, addition of predetermined percentages of coarse sand and fine gravel (or gravel-size crushed glass) to the dredged material will make it suitable for both applications. For drainage layer, it shall be demonstrated that the modified aggregate meets the $10^{-3}$ cm/sec (or higher) permeability requirement.

We understand that currently crushed glass is stockpiled and available in Burlington County for possible blending at the Palmyra Cove site. It is beneficial to collect representative samples from the stockpiled glass and perform gradation analysis to: a) determine the range of particles size present in the stockpiled glass and; b) determine the proportions at which crushed glass and dredged sand to be mixed for each contemplated application. Crushed glass should be washed prior to mixing with dredged sand. In addition, a simple field test needs to be conducted to assess the potential for the glass to be further crushed during spreading and compaction operation.

According to N.J.A.C. 7:26, 2A.7, Geomembranes utilized as an impermeable cap shall be protected from below and above by a minimum thickness of six inches of bedding and cover which is no coarser than a poorly graded sand (SP), as determined in the USCS, and which is free of rocks, fractured stones, debris, cobbles, and solid waste. Samples meeting the above criteria are: STP 2-2, STP 4-1, STP 5-1, STP 6-1, STP 6-3, STP 7-1, and STP 7-2.

Finally, application of dredged sand as landfill vegetative layer was considered. It shall meet the following:
The vegetative layer shall be thick enough to contain the effective root depth or irrigation depth for the type of vegetation planted. The bottom 4 inches of the soil for vegetation shall also be considered as a filter layer for the protection of the drainage layer from plugging. The filter shall be in conformance with N.J.A.C. 7:26, 2A requirements such as:

- $D_{15,\ filter} < (4\ to\ 5)\ D_{85,\ base\ soil\ for\ vegetation}$
- $D_{15,\ filter} > 4\ D_{15,\ base\ soil\ for\ vegetation}$
- $D_{15,\ drainage} < (4\ to\ 5)\ D_{15,\ filter}$
- $D_{15,\ drainage} > 4\ D_{15,\ filter}$

Once the gradation of a base soil is determined, then a determination of conformance can be made of the dredged sand. Blends of material may meet filter layer criteria for specific base soil types.

### 5.4 Embankment

Several analyses were employed to evaluate suitability of the dredged material for stability on slopes. For the purpose of these evaluations, conservatively, cohesion forces were neglected. Using common methods, including equations and chart solutions, for evaluating stability of infinite slopes assuming water is seeping through this material, it would be critically stable at a slope of 15 degrees (approximately 6.5 feet of horizontal distance for every 1 foot of vertical rise or 6.5:1). If a Safety Factor (the ratio of total forces resisting failure to those driving failure) of 1.5 is used, the slope would be 8 degrees (12:1). If the conditions are dry, then the slope would be critically stable at an angle of 37 degrees (2.6:1). If a Safety Factor of 1.5 is used, then the maximum slope would be 27 degrees (3.6:1).

### 5.5 Retaining Walls/ Reinforced Slopes

A potential application for the dredged sand is backfill behind retaining walls or for the reinforced slopes. Retaining wall backfill should allow drainage of percolated water away from the wall to eliminate development of hydrostatic forces that contribute to instability of the wall. The backfill also should exhibit high friction angle to minimize the lateral loads exerted on the wall. Granular soils with permeability in the order of $10^{-3}$ cm/sec or higher allow for fair drainage. Among fifteen samples tested, five with fine contents less than 7% exhibited permeability of 1 x $10^{-3}$ cm/sec. or higher. Meanwhile, the friction angle for those samples ranged from 36 to 39 degrees indicating the dredged sand exhibits high fictional resistance and thus is suitable for retaining wall application.

As for reinforced slopes application, the two property of concern for the fill are shear strength and permeability. Granular materials which provide fair drainage and high friction angle are considered ideal as backfill or reinforced slope application. This material lends itself very favorably to a variety of reinforced earth applications including mechanically-stabilized walls (MSEs) and geogrids. Such applications could significantly increase the slope angles for embankments with an acceptable Factor of Safety.

Samples deemed suitable for the retaining wall and reinforced slope application are as follows: STP 1-2, STP 2-2, STP 2-3, STP 4-1, STP 5-1, SP 5-2, STP 6-1, STP 6-3, STP 7-1 and STP 7-2.

## 6.0 Market Analysis

The testing program described above has demonstrated the suitability of this material for the following applications:

- Embankments
- Sub-grade fill
- Sub-base aggregate

The costs associated with the use of this material in different applications include the following components:

- Material cost
- Excavation and stockpiling at the Palmyra location to prepare for loading and transportation
- Loading onto DOT-approved trucks
- Transportation to the construction site and unloading at that site
- Placement and compaction at the construction site, including moisture conditioning as necessary

It should be noted that each of these components would apply to any embankment, sub-grade fill, or sub-base material. Various cost analysis tools are available to estimate costs associated with construction activities. These cost analyses may group costs differently. Our analysis was based on conversations with New Jersey road contractors, and our experience in conjunction with available estimating tools from R.S. Means Inc. and is presented in the Table below:

**Table 11. Cost Comparison Summary**

| **Cost Item** | **Typical DOT-approved material cost ($/cubic yard)** | **Anticipated Palmyra cost ($/cubic yard)** |
|---|---|---|
| Material | 5 –10 | 2.25 |
| Excavation and stockpiling | 1.5 –2 | 1.5 -2 |
| Loading | 1-1.5 | 1-1.5 |
| Transportation | 2 – 7 | 2 – 7 |
| Placement and compaction | 1 – 2 | 1 – 2 |
| Approximate Total | 10 - 22 | 7.75 - 14.75 |

Note: for loose materials under typical moisture conditions, the density would be expected to be about 1.3 to 1.4 tons/cubic yards. For compacted materials, moist densities of 1.4 to 1.5 tons per cubic yard are typical.

The values expressed in Table 11 should be considered preliminary estimates applicable to the Palmyra area at the time of this study. However, they indicate a favorable comparison between Palmyra dredged material and comparable DOT-approved materials from other sources, based on our experience and discussions with local earthwork contractors. A brief explanation of the assumptions and key factors for each of the cost categories follows:

### 6.1 Material costs:

The unit cost for clean soils (meeting NJDEP Residential Direct Contact Soil Cleanup Criteria, RDCSCC) varies based on market forces, seasonal factors, and other regional factors. Current material purchase price for the dredged sediments is $ 2.25/cy (Robert Shinn, 2005).

The cost for approved transportation-grade materials varies but there is often an added value in materials that have been certified clean for environmental contaminants by the supplier. This added value may increase the cost commanded for the material by $1-2 per cubic yard of material. Additionally, the current level of geotechnical testing may increase the value of the material over similar less tested materials.

Since a variety of other costs are incurred to use these sediments, the price commanded for sediments will be partially driven by the related costs such as transportation, loading and unloading, etc.

### 6.2 Excavation and Stockpiling

This is the one cost category where the Palmyra material may be slightly more expensive than comparable materials. The Palmyra material is spread out over a large site and will require the removal of surface vegetation in some areas prior to use on construction sites. This cost is also highly dependent on the volume of material that may be required for a particular project, since there are large economies of scale with earthwork operations. We understand that there is a limit on the volume of material that may be removed per year of 100,000 cubic yards due to restrictions put by local authorities on the number of trucks allowed to go over the access bridge to the Palmyra site annually. This limit may prohibit the possibility of some advantages of scale associated with this large stockpile.

### 6.3 Transportation

Transportation cost of soil aggregate is mostly dictated by the distance and/or travel time to the disposal site. Two Class B recycling facility operators were consulted to determine the current market rates for soil transportation. The following rates are applied to soils that are transportable at their natural moisture contents and no specific provision for trucking is required.

Typically a tri-axle truck can travel between 200 to 300 miles per day transporting 20 cubic yards (cy) of soil per trip. The travel distance highly depends on the accessibility of borrow and the disposal site and type of roads connecting the two sites. Other factors affecting this rate are loading time, ease of access to borrow and unloading spot and hours of operation (day vs. night).

The current rate for a tri-axle truck is $800 to $1,000 per day (Union rates). This rate could vary based on supply and demand during construction season and off-season. Using the above data, the approximate transportation unit cost for various distances could be as follows:

| **Radius (Miles)** | **Cost per cubic yards Worst Case** | **Cost per cubic yards Best Case** |
|---|---|---|
| 20 | $10 | $6.50 |
| 50 | $25 | $15 |
| 100 | ---- | $30 |

The price per cubic yards for loading based on the current rates could be in the range of $1 to $2.

### 6.4 Placement and Compaction

For earthwork on large sites, these are typical costs. However, they are dependent upon:

- The degree or compaction (i.e. 90 or 95% compaction)
- The amount of edge work (i.e. trenches or pad corners) relate to open areas for placement
- Moisture conditioning required based on the site and season

### 6.5 Volume Projections

Engineering estimates associated with the volume of material present at the Palmyra site was not in our scope of work. However, based on typical depths of sediments over the area of the site, we estimate that the volume present is approximately 450,000 cubic yards. We understand that current agreements limit the volume of material removed at 100,000 cubic yards per year (Robert Shinn, personal communication).

## 7.0 Conclusions and Recommendations

Based on the findings of this study, it is our opinion that the dredged material at the Palmyra Cove is suitable for the following applications:

- Roadway sub-base
- Embankment earth fill
- Retaining wall backfill
- Pipe trench bedding
- General earth fill

The geotechnical test results associated with these applications compare favorably to applicable criteria established by federal and state agencies. Additionally, the results compare favorably to those of native soils excavated in New Jersey. The environmental testing results indicate that the soils meet RDCSCC in the State of New Jersey. Although criteria of other states were not evaluated, it is our opinion that results will be very similar for other states. Applicable criteria in New Jersey for transportation applications and environmental considerations are generally stricter higher than that of other states.

It is our opinion that, if blended with other suitable materials, the Palmyra material be used for the following applications:

- Landfill cover (above clay cap)
- Landfill drainage layer

For these applications, site-specific considerations and additional testing will be required.

We do not recommend further testing at this time. Based on the relative consistency of the results, the material should be considered for possible applications; appropriate testing can be performed for those applications, as necessary.

### *Decision Tree*

We have provided a decision tree (Appendix B) that can be used for determination of beneficial use potential for dredged sediments contained in other CDFs throughout New Jersey. This decision tree is based on previous work at Rutgers University and the work of Douglas et al (2003).

A CDF proposed for beneficial use evaluation would be sampled for both chemical and physical characteristics similar to what was performed in this study. If chemical characteristics indicate that the material meets NJRDCSCC, then the material could be used without environmental restrictions. Material failing these criteria could still be used, but would need to be used on a regulated facility such as a landfill. Once chemical characteristics have been established, the potential uses can easily be evaluated using the standard physical criteria used for all quarried materials. The most common applications for dredged sediments are envisioned to be transportation applications including road base and embankments, common structural or non-structural fill or incorporation into waste containment facilities (for contaminated materials).

Since it is possible to mix the dredged material with other waste and aggregate materials to generate an essentially infinite array of physical properties, they were not all included in the decision tree. Ease of mixing increases with decreasing content of silt and clay. For this case, the Palmyra sediments lend themselves to mixing with a variety of materials and generation of a wide variety of products.

It should be noted that this decision tree provides a structure for evaluating generic applications. Specific projects may require application-specific considerations

## REFERENCES


American Association of State Highway and Transportation Officials (AASHTO). 1996. Standard Test Method for Determining the Resilient Modulus of Soils and Aggregate Materials, AASHTO Designation TP46-94.

American Society for Testing and Materials (ASTM). 2005. Volume 4.08 Soil and Rock, Philadelphia, PA

Douglas, W.S., Baier, L.J., Gimello, R.J., Lodge J. 2003. A Comprehensive Strategy for Managing Contaminated Dredged Material in the Port of NY and NJ, *J. Dredging Eng.* 5(3):1-12.

Freeze, R. Allen and Cherry, John A. 1979. Groundwater, Prentice-Hall, Englewood Cliffs, NJ.

Rutgers University Department of Civil and Environmental Engineering, 2001, Geotechnical Testing and Beneficial Reuse Evaluation Proposal, Palmyra Cove Delaware River Sediments, Burlington County, New Jersey, November 19.

Shinn, Robert, S2 Concepts. 2003. Personal communication based on records of sale for Palmyra material, April 7.

Shinn, Robert, S2 Concepts. 2004. Personal communications, December 3.

State of New Jersey. 2002 (re-adoption with amendments 2004). Administrative Code, Subtitle 7, Chapter 26: Technical Requirements for Site Remediation.

State of New Jersey Department of Transportation (NJDOT). 1996. Standard Specifications for Road and Bridge Construction.

State of New Jersey Department of Transportation (NJDOT), 1998 Supplemental Specifications to the 1996 Standard Specifications for Road and Bridge Construction

# Tables

**Summary of Test Results and Compliance with NJDOT Standards**
**Palmyra Cove Dredged Sediments Beneficial Reuse Evaluation**
**Palmyra, New Jersey**

| | Gradation | | Strength | | Permeability cm/s | | Soil-Ag Grad |
|---|---|---|---|---|---|---|---|
| *Sample* | *% Sand* | *%Silt & Clay* | *C (psi)* | *φ °* | *Rigid* | *Flex* | *Compliance* |
| STP 1-1 | 90.8 | 9.2 | 2.1 | 38 | 3.85E-04 | 3.68E-04 | *I-11, I-12, I-13* |
| STP 1-2 | 93.2 | 6.8 | 1.4 | 38 | 1.53E-03 | 1.48E-03 | *I-13* |
| STP 1-3 | 84.1 | 15.7 | 1.8 | 39 | 5.06E-04 | 6.30E-04 | *none* |
| STP 2-1 | 83.6 | 15.3 | 3.0 | 39 | 6.24E-05 | 6.25E-05 | *none* |
| STP 2-2 | 98.5 | 1.5 | 0.8 | 39 | 8.47E-03 | 8.10E-03 | *I-11, I-12, I-13* |
| STP 2-3 | 87.6 | 12.4 | 2.2 | 38 | 2.43E-03 | 2.33E-03 | *I-13* |
| STP 3-1 | 64.1 | 35.8 | 2.7 | 37 | 5.89E-04 | 5.87E-04 | *none* |
| STP 4-1 | 98.9 | 0.4 | 1.7 | 36 | 1.87E-02 | 1.80E-02 | *I-11, I-12, I-13* |
| STP 5-1 | 98.2 | 0.9 | 1.0 | 36 | 1.78E-02 | 1.75E-02 | *I-11, I-12, I-13* |
| STP 5-2 | 93.5 | 6.0 | 1.8 | 39 | 1.90E-03 | 1.89E-03 | *I-11, I-12, I-13* |
| STP 6-1 | 97.3 | 2.7 | 1.5 | 36 | 5.38E-03 | 5.08E-03 | *I-11, I-12, I-13* |
| STP 6-3 | 99.1 | 0.8 | 0.9 | 38 | 1.67E-02 | 1.38E-02 | *I-11, I-12, I-13* |
| STP 7-1 | 98.6 | 1.3 | 1.0 | 37 | 7.31E-03 | 7.41E-03 | *I-11, I-12, I-13* |
| STP 7-2 | 98.5 | 1.3 | 0.9 | 39 | 7.72E-03 | 7.94E-03 | *I-11, I-12, I-13* |
| STP 8-1 | 78.0 | 21.2 | 2.3 | 37 | 1.47E-04 | 1.25E-04 | *none* |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Mean Values** | **90.9** | **10** | **1.67** | **37.73o** | **5.97E-03** | **5.69E-03** |
| **Std. Deviation** | **10.0** | **8.74** | **0.69** | **1.16o** | | |

Notes:

Samples were tested by the Consolidated-Undrained triaxial method to determine the friction angle and cohesion
The percent sand, silt, and clay is based on sieve results in accordance with ASTM Method D422
Cohesion values are expressed in pounds per square inch (psi) 1psi = 144 pounds per square foot (psf)

**Table 4**

# Summary of the Grain Size Distribution and Specific Gravity Results

## Palmyra Cove Dredged Sediments Beneficial Reuse Evaluation

## Palmyra, New Jersey

| Sample | | % Sand | % Silt & Clay | | $C_U$ | $C_C$ | | $G_S$ |
|---|---|---|---|---|---|---|---|---|
| STP 1-1 | | 90.7 | 9.1 | | 3.14 | 1.11 | | 2.69 |
| STP 1-2 | | 93.1 | 6.8 | | 2.57 | 0.83 | | 2.70 |
| STP 1-3 | | 84.1 | 15.7 | | ….. | ….. | | 2.68 |
| STP 2-1 | | 83.6 | 15.3 | | ….. | ….. | | 2.67 |
| STP 2-2 | | 98.5 | 1.5 | | 2.28 | 1.03 | | 2.68 |
| STP 2-3 | | 87.6 | 12.4 | | ….. | ….. | | 2.68 |
| STP 3-1 | | 64.1 | 35.8 | | ….. | ….. | | 2.60 |
| STP 4-1 | | 98.9 | 0.4 | | 3.80 | 1.6 | | 2.68 |
| STP 5-1 | | 98.2 | 0.9 | | 3.20 | 0.99 | | 2.70 |
| STP 5-2 | | 93.5 | 6.0 | | 3.38 | 1.02 | | 2.65 |
| STP 6-1 | | 97.3 | 2.7 | | 3.05 | 0.99 | | 2.68 |
| STP 6-3 | | 99.1 | 0.8 | | 2.71 | 0.97 | | 2.66 |
| STP 7-1 | | 98.6 | 1.3 | | 2.12 | 0.98 | | 2.67 |
| STP 7-2 | | 98.5 | 1.3 | | 2.27 | 1.02 | | 2.69 |
| STP 8-1 | | 78.0 | 21.2 | | ….. | ….. | | 2.67 |

***Notes:***

* STP 1-1 refers to "Study Test Pit", location and sample depth interval.
* Grain Size distribution analysis were performed in accordance with ASTM D 421.
* Specific gravity of solids testing were performed in accordance with ASTM D 854-92.
* $C_U$ : Coefficient of uniformity (Cu = D60/D10)
* Cc : Coefficient of curvature [Cc=(D30)2/D10*D60]
* Testing was performed at the Rutgers University, Department of Civil and Environmental Engineering, Geotechnical Testing Laboratory in April 2002.

**Table 5**

## Summary of Laboratory Compaction Test Results

### Palmyra Cove Dredged Sediments Beneficial Reuse Evaluation

### Palmyra, New Jersey

| Sample | $\%\omega$ | $\gamma_{d\,max}$ |
|---|---|---|
| STP 1-1 | 14 | 105 |
| STP 1-2 | 18 | 101 |
| STP 1-3 | 16 | 101 |
| STP 2-1 | 11 | 114 |
| STP 2-2 | 19 | 99 |
| STP 2-3 | 18 | 99 |
| STP 3-1 | 19 | 90 |
| STP 4-1 | 19 | 101 |
| STP 5-1 | 18 | 100 |
| STP 5-2 | 17 | 99 |
| STP 6-1 | 19 | 100 |
| STP 6-3 | 18 | 101 |
| STP 7-1 | 18 | 98 |
| STP 7-2 | 19 | 99 |
| STP 8-1 | 11 | 113 |

***Notes:***

* $\omega$ is *optimum moisture content (% water by weight).*

* $\gamma_{d\,MAX}$ is *Maximum dry unit weight of soil* in pounds per cubic foot (*pcf).*

* STP refers to "Study Test Pit".

* STP 1-1 refers to sample location 1 at the first depth interval sampled.

* All tests were performed in accordance with the Standard Proctor Method *(ASTM D 698-91)* at the Rutgers University, Department of Civil and Environmental Engineering, Geotechnical Testing Laboratory in May and June 2002.

**Table 6**

# Summary of Permeability Test Results

**Palmyra Cove Dredged Sediments Beneficial Reuse Evaluation**
**Palmyra, New Jersey**

| | Rigid Wall Method | | Flexible Wall Method | |
|---|---|---|---|---|
| ***Sample*** | ***cm/sec*** | ***ft/day*** | ***cm/sec*** | ***ft/day*** |
| STP 1-1 | 3.85E-04 | 1.1 | 3.68E-04 | 1.0 |
| STP 1-2 | 1.53E-03 | 4.3 | 1.48E-03 | 4.2 |
| STP 1-3 | 5.06E-04 | 1.4 | 6.30E-04 | 1.8 |
| STP 2-1 | 6.24E-05 | 0.18 | 6.24E-05 | 0.18 |
| STP 2-2 | 8.47E-03 | 23.7 | 8.10E-03 | 23.0 |
| STP 2-3 | 2.43E-03 | 6.9 | 2.33E-03 | 6.6 |
| STP 3-1 | 5.89E-04 | 1.7 | 5.87E-04 | 1.7 |
| STP 4-1 | 1.87E-02 | 53.4 | 1.80E-02 | 51.2 |
| STP 5-1 | 1.78E-02 | 50.3 | 1.75E-02 | 49.6 |
| STP 5-2 | 1.90E-03 | 5.4 | 1.89E-03 | 5.4 |
| STP 6-1 | 5.38E-03 | 15.2 | 5.08E-03 | 14.4 |
| STP 6-3 | 1.67E-02 | 47.4 | 1.38E-02 | 39.0 |
| STP 7-1 | 7.31E-03 | 20.7 | 7.41E-03 | 21.0 |
| STP 7-2 | 7.72E-03 | 21.8 | 7.94E-03 | 22.5 |
| STP 8-1 | 1.47E-04 | 0.4 | 1.25E-04 | 0.4 |

***Notes:***

***** STP refers to "Study Test Pit".
* STP 1-1 refers to sample location 1 at the first depth interval sampled.
* Rigid wall tests were performed in accordance with ASTM Method D5856
* Flexible wall tests were performed in accordance with ASTM Method D5084
All testing was performed at the Rutgers University, Department of Civil and
Environmental Engineering, Geotechnical Testing Laboratory in May and June 2002.

**Table 7**

# Comparison Between Permeability Test Results and Gradation Results

**Palmyra Cove Dredged Sediments Beneficial Reuse Evaluation**

| | Permeability (rigid wall) | | Gradation | |
|---|---|---|---|---|
| ***Sample*** | ***cm/sec*** | ***ft/day*** | ***% Sand*** | ***% Silt & Clay*** |
| STP 1-1 | 3.85E-04 | 1.1 | 90.7 | 9.1 |
| STP 1-2 | 1.53E-03 | 4.3 | 93.1 | 6.8 |
| STP 1-3 | 5.06E-04 | 1.4 | 84.1 | 15.7 |
| STP 2-1 | 6.24E-05 | 0.18 | 83.6 | 15.3 |
| STP 2-2 | 8.47E-03 | 23.7 | 98.5 | 1.5 |
| STP 2-3 | 2.43E-03 | 6.9 | 87.6 | 12.4 |
| STP 3-1 | 5.89E-04 | 1.7 | 64.1 | 35.8 |
| STP 4-1 | 1.87E-02 | 53.4 | 98.9 | 0.4 |
| STP 5-1 | 1.78E-02 | 50.3 | 98.2 | 0.9 |
| STP 5-2 | 1.90E-03 | 5.4 | 93.5 | 6.0 |
| STP 6-1 | 5.38E-03 | 15.2 | 97.3 | 2.7 |
| STP 6-3 | 1.67E-02 | 47.4 | 99.1 | 0.8 |
| STP 7-1 | 7.31E-03 | 20.7 | 98.6 | 1.3 |
| STP 7-2 | 7.72E-03 | 21.8 | 98.5 | 1.3 |
| STP 8-1 | 1.47E-04 | 0.4 | 78.0 | 21.2 |

***Notes:***

STP refers to "Study Test Pit".

STP 1-1 refers to sample location 1 at the first depth interval sampled.

All tests were performed on samples compacted to 90-95% of maximum laboratory compaction in accordance with the Standard Proctor Method *(ASTM D 5856-95)* at the Rutgers University, Department of Civil and Environmental Engineering, Geotechnical Testing Laboratory in July 2002.

**Table 8**

# Summary of Triaxial Strength Test Results with Gradation Results

**Palmyra Cove Dredged Sediments Beneficial Reuse Evaluation**

**Palmyra, New Jersey**

| | Triaxial | | Gradation | |
|---|---|---|---|---|
| ***Sample*** | $\phi$ ° | *C (psi)* | *% Sand* | *% Silt & Clay* |
| STP 1-1 | 38 | 2.1 | 90.7 | 9.1 |
| STP 1-2 | 38 | 1.4 | 93.1 | 6.8 |
| STP 1-3 | 39 | 1.8 | 84.1 | 15.7 |
| STP 2-1 | 39 | 3.0 | 83.6 | 15.3 |
| STP 2-2 | 39 | 0.8 | 98.5 | 1.5 |
| STP 2-3 | 38 | 2.2 | 87.6 | 12.4 |
| STP 3-1 | 37 | 2.7 | 64.1 | 35.8 |
| STP 4-1 | 36 | 1.7 | 98.9 | 0.4 |
| STP 5-1 | 36 | 1.0 | 98.2 | 0.9 |
| STP 5-2 | 39 | 1.8 | 93.5 | 6.0 |
| STP 6-1 | 36 | 1.5 | 97.3 | 2.7 |
| STP 6-3 | 38 | 0.9 | 99.1 | 0.8 |
| STP 7-1 | 37 | 1.0 | 98.6 | 1.3 |
| STP 7-2 | 39 | 0.9 | 98.5 | 1.3 |
| STP 8-1 | 37 | 2.3 | 78.0 | 21.2 |

| | | |
|---|---|---|
| **Average values** | **37.73°** | **1.67** |
| **Std. Deviation** | **1.16°** | **0.69** |

Notes:

STP refers to study test pit location and depth.(thus STP 1-1 refers to test pit 1 at the shallowest depth)

Samples compacted to 90-95% were tested by the Consolidated-Undrained triaxial method to determine the friction angle and cohesion value

The percent sand, silt, and clay is based on sieve results in accordance with ASTM Method D422

Cohesion values are expressed in pounds per square inch (psi) 1psi = 144 pounds per square foot (psf)

Table 9

## Summary of CBR Test Results

**Palmyra Cove Dredged Sediments Beneficial Reuse Evaluation**

**Palmyra, New Jersey**

| Sample | CBR @ 0.1 in | | CBR @ 0.2 in | | CBR @ 0.1 in | CBR @ 0.2 in | CBR |
|---|---|---|---|---|---|---|---|
| | Sample 1 | Sample 2 | Sample 1 | Sample 2 | (Average) | (Average) | |
| STP 1-1 | 30.2 | 29.9 | 37.7 | 36.9 | 30.1 | 37.3 | 37.3 |
| STP 1-2 | 15.1 | 17.2 | 20.1 | 23.3 | 16.2 | 21.7 | 21.7 |
| STP 1-3 | 19.9 | 19.3 | 25.9 | 26.3 | 19.6 | 26.1 | 26.1 |
| STP 2-1 | 44.2 | 44.3 | 52.5 | 52.2 | 44.3 | 52.4 | 52.4 |
| STP 2-2 | 13.0 | 16.7 | 17.2 | 22.1 | 14.9 | 19.7 | 19.7 |
| STP 2-3 | 14.5 | 17.5 | 21.0 | 23.3 | 16.0 | 22.2 | 22.2 |
| STP 3-1 | 13.4 | 17.6 | 17.5 | 23.0 | 15.5 | 20.3 | 20.3 |
| STP 4-1 | 18.5 | 19.0 | 25.3 | 23.8 | 18.8 | 24.6 | 24.6 |
| STP 5-1 | 19.0 | 18.4 | 24.1 | 24.7 | 18.7 | 24.4 | 24.4 |
| STP 5-2 | 15.5 | 12.4 | 19.3 | 17.2 | 14.0 | 18.3 | 18.3 |
| STP 6-1 | 14.2 | 13.4 | 19.1 | 18.1 | 13.8 | 18.6 | 18.6 |
| STP 6-3 | 15.9 | 17.0 | 20.1 | 23.1 | 16.5 | 21.6 | 21.6 |
| STP 7-1 | 16.7 | 16.3 | 22.0 | 21.3 | 16.5 | 21.7 | 21.7 |
| STP 7-2 | 19.4 | 19.5 | 25.5 | 26.1 | 19.5 | 25.8 | 25.8 |
| STP 8-1 | 26.8 | 29 | 34.5 | 38.1 | 28.0 | 36.3 | 36.3 |

Notes: CBR Testing was performed in accordance with ASTM D1883 at the Rutgers University Dept. of Civil and Environmental Engineering Geotechnical Testing Laboratory

# APPENDIX A

## Unified Soil Classification Chart (USCS) &
## NJDOT Table 901-2 Standard Soil Aggregate Gradation

| UNIFIED SOIL CLASSIFICATION AND SYMBOL CHART | | |
|---|---|---|
| COARSE-GRAINED SOILS (more than 50% of material is larger than No. 200 sieve size.) | | |
| | Clean Gravels (Less than 5% fines) | |
| **GRAVELS** More than 50% of coarse fraction larger than No. 4 sieve size | GW | Well-graded gravels, gravel-sand mixtures, little or no fines |
| | GP | Poorly-graded gravels, gravel-sand mixtures, little or no fines |
| | Gravels with fines (More than 12% fines) | |
| | GM | Silty gravels, gravel-sand-silt mixtures |
| | GC | Clayey gravels, gravel-sand-clay mixtures |
| | Clean Sands (Less than 5% fines) | |
| **SANDS** 50% or more of coarse fraction smaller than No. 4 sieve size | SW | Well-graded sands, gravelly sands, little or no fines |
| | SP | Poorly graded sands, gravelly sands, little or no fines |
| | Sands with fines (More than 12% fines) | |
| | SM | Silty sands, sand-silt mixtures |
| | SC | Clayey sands, sand-clay mixtures |
| FINE-GRAINED SOILS (50% or more of material is smaller than No. 200 sieve size.) | | |
| **SILTS AND CLAYS** Liquid limit less than 50% | ML | Inorganic silts and very fine sands, rock flour, silty of clayey fine sands or clayey silts with slight plasticity |
| | CL | Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays |
| | OL | Organic silts and organic silty clays of low plasticity |
| **SILTS AND CLAYS** Liquid limit 50% or greater | MH | Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts |
| | CH | Inorganic clays of high plasticity, fat clays |
| | OH | Organic clays of medium to high plasticity, organic silts |
| **HIGHLY ORGANIC SOILS** | PT | Peat and other highly organic soils |

| LABORATORY CLASSIFICATION CRITERIA | | |
|---|---|---|
| GW | $C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{D_{30}}{D_{10} \times D_{60}}$ between 1 and 3 | |
| GP | Not meeting all gradation requirements for GW | |
| GM | Atterberg limits below "A" line or P.I. less than 4 | Above "A" line with P.I. between 4 and 7 are borderline cases requiring use of dual symbols |
| GC | Atterberg limits above "A" line with P.I. greater than 7 | |
| SW | $C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{D_{30}}{D_{10} \times D_{60}}$ between 1 and 3 | |
| SP | Not meeting all gradation requirements for GW | |
| SM | Atterberg limits below "A" line or P.I. less than 4 | Limits plotting in shaded zone with P.I. between 4 and 7 are borderline cases requiring use of dual symbols. |
| SC | Atterberg limits above "A" line with P.I. greater than 7 | |

Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows:

Less than 5 percent .................................. GW, GP, SW, SP
More than 12 percent ................................ GM, GC, SM, SC
5 to 12 percent .................. Borderline cases requiring dual symbols

**PLASTICITY CHART**

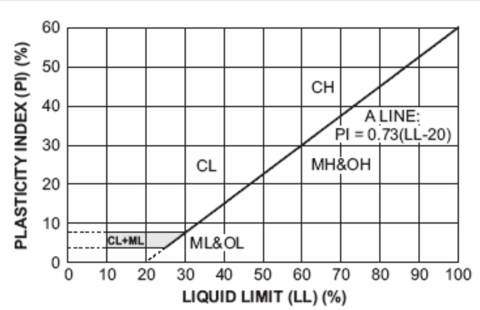


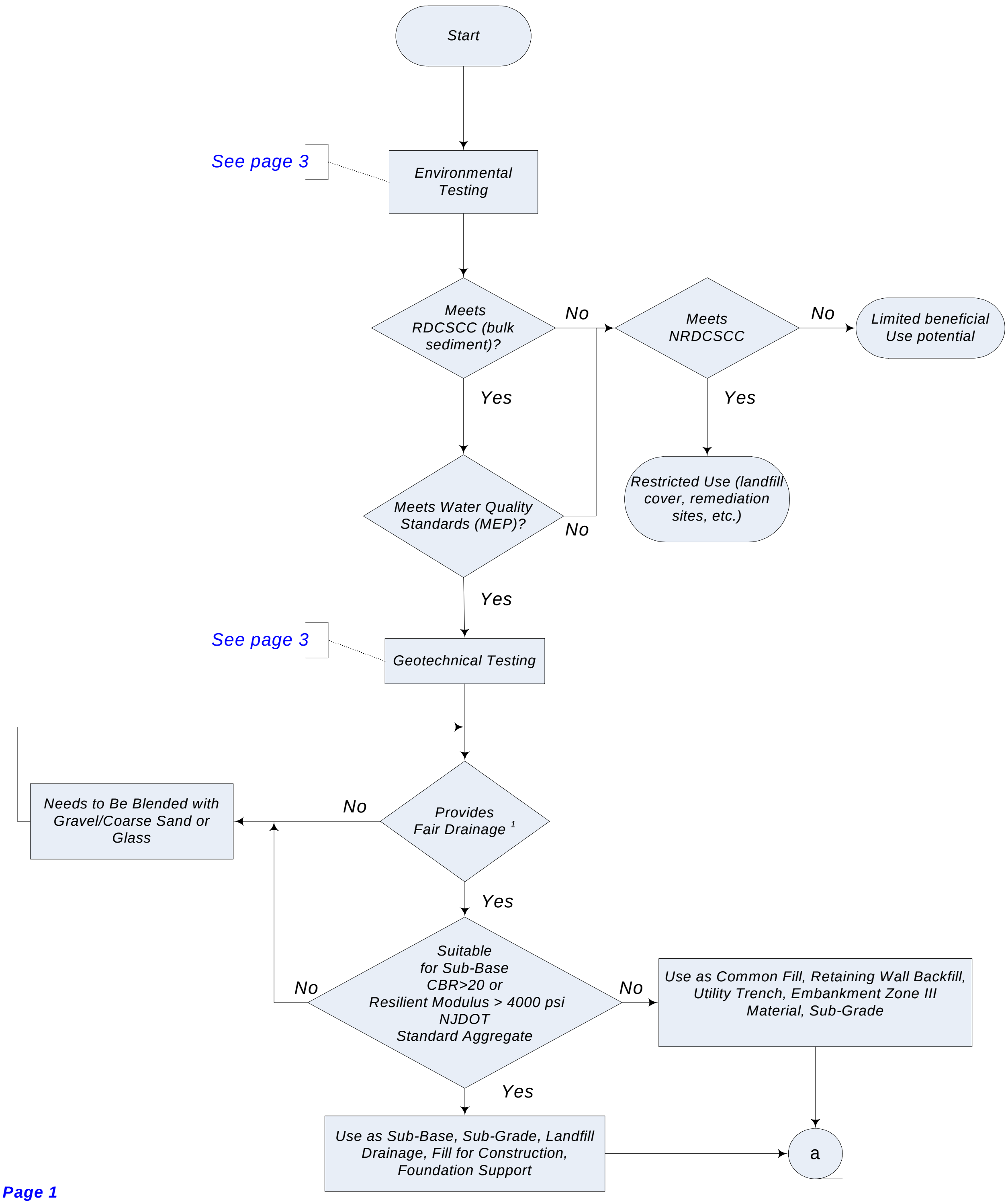
**Table 901-2 Standard Soil Aggregate Gradations**
**New Jersey Interagency Engineering Committee**

| Sieve Size | Gradation Designations, percentage by weight passing square mesh sieves | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **I-1** | **I-2** | **I-3** | **I-4** | **I-5** | **I-6** | **I-7** | **I-8** | **I-9** | **I-10** | **I-11** | **I-12** | **I-13** |
| 4" | 100 | | 100 | | | | | | 100 | 100 | 100 | 100 | 100 |
| 2" | 70-100 | 100 | | 100 | 100 | | | | 80-100 | 80-100 | 80-100 | | |
| 1" | | | | 60-100 | | 100 | 100 | | | | | | |
| ¾" | 50-95 | 65-100 | 60-100 | | 70-100 | | | | 60-100 | 60-100 | 60-100 | 70-100 | |
| ½" | | | | 40-100 | | 80-100 | 80-100 | 100 | | | | | |
| No. 4 | 30-60 | 40-75 | 30-100 | 25-100 | 30-80 | | | 95-100 | 40-100 | 40-100 | 40-100 | | 30-100 |
| No. 8 | | | | 20-100 | | 45-100 | 35-100 | | | | | | |
| No. 16 | | | | 15-85 | | 30-90 | 25-90 | 45-70 | 20-70 | 20-70 | | | |
| No. 50 | 5-25 | 5-30 | 5-35 | 8-45 | 10-35 | 0-20 | 5-50 | 5-25 | 5-35 | 5-40 | 0-75 | 0-75 | |
| No. 100 | | | | | | 0-3 | 0-8 | | 0-20 | 0-30 | | | |
| No. 200 | 0-7 | 0-7 | 0-8 | 5-10 | 5-12 | | 0-2 | 0-5 | 0-8 | 0-20 | 0-9 | 0-5 | 0-12 |

# APPENDIX B

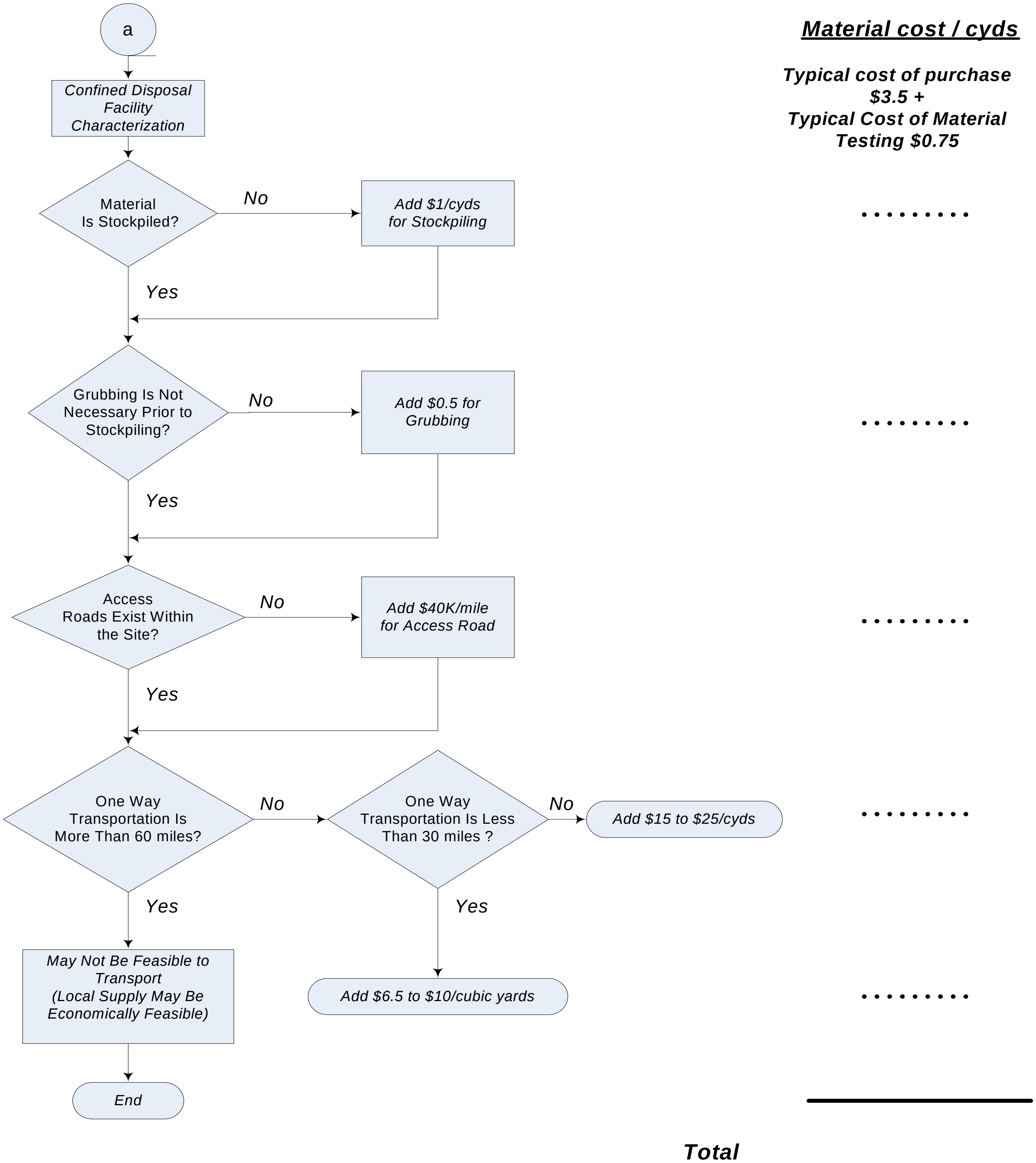
## DECISION TREE TO EVALUATE BENEFICIAL USE ALTERNATIVES FOR DREDGED SEDIMENTS

# Dredged Material Evaluation Plan




**Page 1**

1. Permeability is higher than $10^{-3}$ cm/sec


a
Confined Disposal Facility Characterization
Material Is Stockpiled?
No
Add $1/cyds for Stockpiling
Yes
Grubbing Is Not Necessary Prior to Stockpiling?
No
Add $0.5 for Grubbing
Yes
Access Roads Exist Within the Site?
No
Add $40K/mile for Access Road
Yes
One Way Transportation Is More Than 60 miles?
No
One Way Transportation Is Less Than 30 miles ?
No
Add $15 to $25/cyds
Yes
Yes
May Not Be Feasible to Transport (Local Supply May Be Economically Feasible)
Add $6.5 to $10/cubic yards
End
Material cost / cyds
Typical cost of purchase $3.5 +
Typical Cost of Material Testing $0.75
Total

**Page 2**

*1) Geotechnical Testing:*

*A) Frequency* — *One set of testing at every 5000 cyds*

*B) Identification*
- *Grain size distribution*
- *Plasticity index*
- *Classification*

*C) Engineering*
- *Strength under static & dynamic loading*
  *(tri-axial shear, direct shear, CBR & resilient modulus)*
- *Permeability*
  *(flexible wall method)*
- *Moisture-density relationship*
  *(standard/modified proctor )*

*2) Environmental Testing:*

*A) Frequency* — *One set of testing at every 10000 cyds*

*B) Soil Testing*
- *Sediment Bulk Chemistry*
- *Total Organic Content*
- *Moisture Content*
- *Gradation*

*C) Leachate Testing*
- *Multiple Extraction Procedure(MEP)*

***Page 3***

# APPENDIX C

## NJ DEP Soil Cleanup Criteria

### NJ DEP *Soil Cleanup Criteria (mg/kg)*

This listing represents the combination of Tables 3-2 and 7-1 from the Department of Environmental Protection and Energy's February 3, 1992 proposed rule entitled Cleanup Standards for Contaminated Sites, N.J.A.C. 7:26D, as corrected based upon errors identified by the Department during or subsequent to the comment period as well as new toxicological or other information obtained since the rule proposal

Last Revised - 5/12/99

| Constituent | CASRN | (RDCSCC) | (NRDCSCC) | (IGWSCC) |
|---|---|---|---|---|
| Acenaphthene | 83-32-9 | 3400 | 10000(c) | 100 |
| Acetone (2-propanone) | 67-64-1 | 1000(d) | 1000(d) | 100 |
| Acrylonitrile | 107-13-1 | 1 | 5 | 1 |
| Aldrin | 309-00-2 | 0.04 | 0.17 | 50 |
| Anthracene | 120-12-7 | 10000(c) | 10000(c) | 100 |
| Antimony | 7440-36-0 | 14 | 340 | (h) |
| Arsenic | 7440-38-2 | 20 (e) | 20 (e) | (h) |
| Barium | 7440-39-3 | 700 | 47000(n) | (h) |
| Benzene | 71-43-2 | 3 | 13 | 1 |
| "Benzo(b)fluoranthene (3,4-Benzofluoranthene) " | 205-99-2 | 0.9 | 4 | 50 |
| "Benzo(a)anthracene (1,2-Benzanthracene) " | 56-55-3 | 0.9 | 4 | 500 |
| Benzo(a)pyrene (BaP) | 50-32-8 | 0.66(f) | 0.66(f) | 100 |
| Benzo(k)fluoranthene | 207-08-9 | 0.9 | 4 | 500 |
| Benzyl Alcohol | 100-51-6 | 10000(c) | 10000(c) | 50 |
| Beryllium | 7440-41-7 | [1(f)] 2 (e) | [1(f)] 2 (e) | (h) |
| Bis(2-chloroethyl) ether | 111-44-4 | 0.66(f) | 3 | 10 |

| | | | | |
|---|---|---|---|---|
| **Bis(2-chloroisopropyl)ether** | 108-60-1 | 2300 | 10000(c) | 10 |
| **Bis(2-ethylhexyl) phthalate** | 117-81-7 | 49 | 210 | 100 |
| **Bromodichloromethane (Dichlorobromomethane)** | 75-27-4 | 11 | 46 | 1 |
| **Bromoform** | 75-25-2 | 86 | 370 | 1 |
| **Bromomethane (Methyl bromide)** | 74-83-9 | 79 | 1000 (d) | 1 |
| **2-Butanone (Methyl ethyl ketone) (MEK)** | 78-93-3 | 1000 (d) | 1000 (d) | 50 |
| **Butylbenzyl phthalate** | 85-68-7 | 1100 | 10000 (c) | 100 |
| **Cadmium** | 7440-43-9 | [1] 39 | 100 | (h) |
| **Carbon tetrachloride** | 56-23-5 | 2 (k) | 4 (k) | 1 |
| **4-Chloroaniline (p-Chloroaniline)** | 106-47-8 | 230 | 4200 | (r) |
| **Chlorobenzene** | 108-90-7 | 37 | 680 | 1 |
| **Chloroform** | 67-66-3 | 19 (k) | 28 (k) | 1 |
| **4-Chloro-3-methyl phenol (p-Chloro-m-cresol)** | 59-50-7 | 10000 (c) | 10000 (c) | 100 |
| **Chloromethane (Methyl chloride)** | 74-87-3 | 520 | 1000 (d) | 10 |
| **2-Chlorophenol (o-Chlorophenol)** | 95-57-8 | 280 | 5200 | 10 |
| **Chromium – hexavalent (VI)** | 18540-29-9 | 240; 270 (g); (i) | 6100; 20 (g); (i) | (h) |
| **Chromium – trivalent (III)** | 16065-83-1 | "120,000" | (j) | (l) |
| **Chrysene** | 218-01-9 | 9 | 40 | 500 |
| **Copper** | 7440-50-8 | 600 (m) | 600 (m) | (h) |
| **Cyanide** | 57-12-5 | 1100 | 21000 (o) | (h) |
| **"4,4'-DDD (p,p'-TDE) "** | 72-54-8 | 3 | 12 | 50 |
| **"4,4'-DDE (p,p'-DDX) "** | 72-55-9 | 2 | 9 | 50 |
| **"4,4'-DDT "** | 50-29-3 | 2 | 9 | 500 |

| | | | | |
|---|---|---|---|---|
| **"Dibenz(a,h)anthracene "** | 53-70-3 | 0.66 (f) | 0.66 (f) | 100 |
| **Dibromochloromethane (Chlorodibromomethane)** | 124-48-1 | 110 | 1000 (d) | 1 |
| **Di-n-butyl phthalate** | 84-74-2 | 5700 | 10000 (c) | 100 |
| **Di-n-octyl phthalate** | 117-84-0 | 1100 | 10000 (c) | 100 |
| **"1,2-Dichlorobenzene (o-Dichlorobenzene) "** | 95-50-1 | 5100 | 10000 (c) | 50 |
| **"1,3-Dichlorobenzene (m-Dichlorobenzene) "** | 541-73-1 | 5100 | 10000 (c) | 100 |
| **"1,4-Dichlorobenzene (p-Dichlorobenzene) "** | 106-46-7 | 570 | 10000 (c) | 100 |
| **"3,3'-Dichlorobenzidine "** | 91-94-1 | 2 | 6 | 100 |
| **"1,1-Dichloroethane "** | 75-34-3 | 570 | 1000 (d) | 10 |
| **"1,2-Dichloroethane "** | 107-06-2 | 6 | 24 | 1 |
| **"1,1-Dichloroethene "** | 75-35-4 | 8 | 150 | 10 |
| **"1,2-Dichloroethene (trans) "** | 156-60-5 | 1000 (d) | 1000 (d) | 50 |
| **"1,2-Dichloroethene (cis) "** | 156-59-2 | 79 | 1000 (d) | 1 |
| **"2,4-Dichlorophenol "** | 120-83-2 | 170 | 3100 | 10 |
| **"1,2-Dichloropropane "** | 78-87-5 | 10 | 43 | (r) |
| **"1,3-Dichloropropene(cis and trans) "** | 542-75-6 | 4 | 5 (k) | 1 |
| **Dieldrin** | 60-57-1 | 0.042 | 0.18 | 50 |
| **Diethyl phthalate** | 84-66-2 | 10000 (c) | 10000 (c) | 50 |
| **"2,4-Dimethyl phenol "** | 105-67-9 | 1100 | 10000 (c) | 10 |
| **Dimethyl phthalate** | 131-11-3 | 10000 (c) | 10000 (c) | 50 |
| **"2,4-Dinitrophenol "** | 51-28-5 | 110 | 2100 | 10 |
| **"Dinitrotoluene(2,4-/2,6-mixture) "** | 25321-14-6 | 1 (l) | 4 (l) | 10 (l) |
| **Endosulfan** | 115-29-7 | 340 | 6200 | 50 |

| | | | | |
|---|---|---|---|---|
| **Endrin** | 72-20-8 | 17 | 310 | 50 |
| **Ethylbenzene** | 100-41-4 | 1000 (d) | 1000 (d) | 100 |
| **Fluoranthene** | 206-44-0 | 2300 | 10000 (c) | 100 |
| **Fluorene** | 86-73-7 | 2300 | 10000 (c) | 100 |
| **Heptachlor** | 76-44-8 | 0.15 | 0.65 | 50 |
| **Hexachlorobenzene** | 118-74-1 | 0.66 (f) | 2 | 100 |
| **Hexachlorobutadiene** | 87-68-3 | 1 | 21 | 100 |
| **Hexachlorocyclopentadiene** | 77-47-4 | 400 | 7300 | 100 |
| **Hexachloroethane** | 67-72-1 | 6 | 100 | 100 |
| **"Indeno(1,2,3-cd)pyrene "** | 193-39-5 | 0.9 | 4 | 500 |
| **Isophorone** | 78-59-1 | 1100 | 10000 (c) | 50 |
| **Lead** | 7439-92-1 | 400 (p) | 600 (q) | (h) |
| **Lindane (gamma BHC) (gamma HCH)** | 58-89-9 | 0.52 | 2.2 | 50 |
| **2-Methylphenol (o-creosol)** | 95-48-7 | 2800 | 10000 (c) | (r) |
| **4-Methylphenol (p-creosol)** | 106-44-5 | 2800 | 10000 (c) | (r) |
| **Methoxychlor** | 72-43-5 | 280 | 5200 | 50 |
| **Mercury** | 7439-97-6 | 14 | 270 | (h) |
| **4-Methyl-2-pentanone (MIBK)** | 108-10-1 | 1000 (d) | 1000 (d) | 50 |
| **Methylene chloride (Dichloromethane)** | 75-09-2 | 49 | 210 | 1 |
| **Naphthalene** | 91-20-3 | 230 | 4200 | 100 |
| **Nickel** | 7440-02-0 | 250 | 2400 (k) (n) | (h) |
| **Nitrobenzene** | 98-95-3 | 28 | 520 | 10 |
| **N-Nitrosodiphenylamine** | 86-30-6 | 140 | 600 | 100 |

| | | | | |
|---|---|---|---|---|
| **N-Nitrosodi-n-propylamine** | 621-64-7 | 0.66 (f) | 0.66 (f) | 10 |
| **PCBs (Polychlorinated biphenyls)** | 1336-36-3 | 0.49 | 2 | 50 |
| **Pentachlorophenol** | 87-86-5 | 6 | 24 | 100 |
| **Phenol** | 108-95-2 | 10000 (c) | 10000 (c) | 50 |
| **Pyrene** | 129-00-0 | 1700 | 10000 (c) | 100 |
| **Selenium** | 7782-49-2 | 63 | 3100 (n) | (h) |
| **Silver** | 7440-22-4 | 110 | 4100 (n) | (h) |
| **Styrene** | 100-42-5 | 23 | 97 | 100 |
| **"1,1,1,2-Tetrachloroethane "** | 630-20-6 | 170 | 310 | 1 |
| **"1,1,2,2-Tetrachloroethane "** | 79-34-5 | 34 | 70 (k) | 1 |
| **Tetrachloroethene (Tetrachloroethylene) (PCE)** | 127-18-4 | 4 (k) | 6 (k) | 1 |
| **Thallium** | 7440-28-0 | 2 (f) | 2 (f) | (h) |
| **Toluene** | 108-88-3 | 1000 (d) | 1000 (d) | 500 |
| **Toxaphene** | 8001-35-2 | 0.10 (k) | 0.2 (k) | 50 |
| **"1,2,4-Trichlorobenzene "** | 120-82-1 | 68 | 1200 | 100 |
| **"1,1,1-Trichloroethane "** | 71-55-6 | 210 | 1000 (d) | 50 |
| **"1,1,2-Trichloroethane "** | 79-00-5 | 22 | 420 | 1 |
| **Trichloroethene (Trichloroethylene) (TCE)** | 79-01-6 | 23 | 54 (k) | 1 |
| **"2,4,5-Trichlorophenol "** | 95-95-4 | 5600 | 10000 (c) | 50 |
| **"2,4,6-Trichlorophenol "** | 88-06-2 | 62 | 270 | 10 |
| **Vanadium** | 7440-62-2 | 370 | 7100 (n) | (h) |
| **Vinyl chloride** | 75-01-4 | 2 | 7 | 10 |
| **Xylenes (Total)** | 1330-20-7 | 410 | 1000 (d) | [10] 67 (s) |

| | | | | |
|---|---|---|---|---|
| **Zinc** | 7440-66-6 | 1500 (m) | 1500 (m) | (h) |

**Footnotes:**

(a) Criteria are health based using an incidental ingestion exposure pathway except where noted below.

(b) Criteria are subject to change based on site specific factors (e.g., aquifer classification, soil type, natural background, environmental impacts, etc.).

(c) Health based criterion exceeds the 10,000 mg/kg maximum for total organic contaminants.

(d) Health based criterion exceeds the 1000 mg/kg maximum for total volatile organic contaminants.

(e) Cleanup standard proposal was based on natural background.

(f) Health based criterion is lower than analytical limits; cleanup criterion based on practical quantitation level.

(g) Criterion based on the inhalation exposure pathway.

(h) The impact to ground water values for inorganic constituents will be developed based upon site specific chemical and physical parameters.

(i) Site specific determination required for SCC for the allergic contact dermatitis exposure pathway.

(j) Contaminant not regulated for this exposure pathway.

(k) Criteria based on inhalation exposure pathway, which yielded a more stringent criterion than the incidental ingestion exposure pathway.

(l) No criterion derived for this contaminant.

(m) Criterion based on ecological (phytotoxicity) effects.

(n) Level of the human health based criterion is such that evaluation for potential environmental impacts on a site by site basis is recommended.

(o) Level of the criterion is such that evaluation for potential acute exposure hazard is recommended.

(p) Criterion based on the USEPA Integrated Exposure Uptake Biokinetic (IEUBK) model utilizing the default parameters. The concentration is considered to protect 95% of target population (children) at a blood lead level of 10 ug/dl.

(q) Criteria were derived from a model developed by the Society for Environmental Geochemistry and Health (SEGH) and were designed to be protective for adults in the workplace.

(r) Insufficient information available to calculate impact to ground water criteria.

(s) Criterion based on new drinking water standard.