Replaces Technical Note DOER-C2
February 1998 (May 1999)

Dredged Material Characterization Tests for Beneficial Use Suitability

PURPOSE: The nature, magnitude, and distribution of contaminants in dredged material vary within and between sites, making consideration of the potential beneficial uses of dredged material more difficult. This technical note provides guidance on the nature and types of physical, engineering, chemical, and biological characterization tests appropriate for determining the potential for beneficial uses of dredged material in aquatic, wetland, and upland environments.

BACKGROUND: The U.S. Army Corps of Engineers (USACE) has the responsibility for maintaining and improving navigation in waters of the United States. More than 300 million cubic meters of sediment are dredged annually to accomplish this task. Most of the dredged material (approximately 90 percent) is considered uncontaminated. However, some waterways are located near areas that are highly industrialized or in urban settings, and the sediments have been contaminated by point and nonpoint sources of metals and anthropogenic organic chemicals [e.g., petroleum aromatic hydrocarbons (PAHs) and/or polychlorinated biphenyls (PCBs)]. Agricultural practices have also contributed to sediment contamination (pesticides, herbicides, fertilizers) in rural areas. Contaminated sediments, unacceptable for open-water placement, are usually placed in confined disposal facilities (CDFs) or confined placement facilities (CPFs). Because many existing CPFs are filled to capacity, finding additional suitable placement sites for dredged material is a growing concern. The USACE/U.S. Environmental Protection Agency (USEPA) technical framework describes the evaluation procedures established for the determination of beneficial uses of dredged material (USACE/USEPA 1992). A beneficial use component is included in that framework and is expanded in this technical note to give additional guidance on its implementation. Alternatives must be developed that can provide beneficial uses for both the contaminated and uncontaminated dredged material in CPFs so that these materials can be removed and used, resulting in the creation of additional CPF storage capacity for future dredging activities.

INTRODUCTION: Dredged material, like soil, is a complex matrix with many dynamic interacting components that can affect more than one property. Adequate assessments of the geotechnical, engineering, chemical, and biological properties must be considered in determining the potential beneficial uses of a dredged material. The properties of a dredged material must be matched to a particular beneficial use. Conditioning dredged material may also be required to produce a material that can perform a beneficial function. A number of physical, engineering, chemical, and biological tests are available to characterize and aid in making decisions about the potential beneficial uses of the dredged material. Appropriate characterization tests are listed in Tables 1-3 of this technical note. Even though most of these analyses were initially designed for soils, they can be applied to dredged material because of its soil-like nature. The terms “soil” and “dredged material” will be used interchangeably throughout this technical note.

Characterization of the dredged material is initiated by an evaluation of its physical properties including (a) grain-size distribution, (b) particle shape, (c) texture, (d) water content, (e) permeability,

Table 1
Appropriate Characterization Tests for Determining Physical and Engineering Properties of Dredged Material to Evaluate Its Suitability for Beneficial Uses

Physical Analysis	Source
1. Grain Size	
Standard Sieve Test	ASTM D422-63; COE V; DOD 2-III, 2-V, 2-VI; CSSS 47.4
Hydrometer Test	ASTM D422-63; CSSS 47.3; COE V
Pipette Test	CSSS 47.2
2. Particle Shape/Texture	ASTM D2488, D4791-95, and D3398-93
3. Water Content/% Moisture	ASTM D2216-92; COE I-1; DOD 2-VII
4. Permeability	ASA: 41-3 and 41-4; ASTM D2434-68
5. Atterberg Limits (Plasticity)	ASTM D4318-9 5; COE III; DOD 2-VIII
6. Organic Content/Organic Matter	ASTM D2487-93
Engineering Properties	**Source**
7. Compaction Tests	
Proctors	COE VI
Standard Compaction Test	ASTM D698-91
Modified Compaction Test	ASTM D1557-91
15 Blow Compaction Test	ASTM D5080-93
California Bearing Ratio	DOD 2-IX
8. Consolidation Tests	COE VIII; ASTM D2435-90
9. Shear Strength	
UU (unconsolidated, undrained)	COE X-18
CU (consolidated, undrained)	COE X-29
CD (consolidated, drained)	COE IX-38

Notes:
ASTM = American Society for Testing and Materials (ASTM 1996).
ASA = American Society of Agronomy/Soil Science Society of America. Method of Soil Analysis, Part-1, 1965.
COE = EM 1110-2-1906 (Headquarters, U.S. Army Corps of Engineers 1986).
CSSS = Canadian Society of Soil Science (Carter 1993).
DOD = U.S. Department of the Army, Navy, and Air Force 1987.

(f) plasticity, and (g) organic content. The engineering properties are used to determine the compactability, consolidation, and shear strength of the dredged material. An assessment of chemical properties can indicate the actions required to (a) obtain the desired pH or salinity, (b) determine a liming requirement to enhance buffering capacity or nutrient availability for plant growth, (c) improve texture, and (d) determine if inorganic (e.g., metals) or organic contaminants (e.g., PAHs, PCBs) are present. Finally, the biological properties must be assessed to (a) evaluate the bioavailability of contaminants to plants and animals, (b) determine the potential for adverse environmental impacts, and (c) determine if control measures or restrictions are required to prevent adverse environmental impacts.

Table 2
Appropriate Characterization Tests for Chemical Properties of Dredged Material to Determine Suitability for Beneficial Uses

Analysis	Source
10. pH	ASA 1996 :Ch 16; CSSS: 16.2.1
11. Calcium Carbonate Equivalents	ASA 1996:Ch 16; CSSS 14.2 and 44.6
12. Cation Exchange Capacity	ASA 1996: Ch 40; CSSS 19.4
13. Salinity	ASA 1996: Ch 14; CSSS:18.2.2
14. Sodium	ASA 1996: Ch 19
15. Chloride	ASA 1996: Ch 31
16. Sodium Adsorption Ratio (SAR)	CSSS: 18.4.3
17. Electrical Conductivity	ASA 1996: Ch 14
18. Total Organic Carbon	ASTM D2974; D2974-87; ASA 1982: 29-4.2; CSSS 44.3
19. Carbon:Nitrogen Ratio	Analyses 19, 23, and 25 in this table
20. Total Kjeldahl Nitrogen	EPA-CRL-468
21. Ammonium Nitrogen	EPA-CRL-324
22. Nitrate-nitrogen	EPA-SW846-9200
23. Nitrite-nitrogen	EPA-SW846-9200
24. Total Phosphorus	EPA-CRL-435
25. Orthophosphorus	EPA-CRL-435
26 Potassium	ASA 1996: Ch 19
27. Sulfur	ASA 1996: Ch 33
28. Diethylene Triamine Pentaacetic Acid (DTPA) Metals	ASA 1982: 19-3.3; CSSS:1.3; Lee, Folsom, and Bates 1983
29. Total Metals *	EPA-SW846-200.9; ASA 1996: Ch 18-30
30. Pesticides (chlorinated)	EPA-SW846-8080
31. Polynuclear Aromatic Hydrocarbons (PAHs)	EPA- SW846-8270
32. Polychlorinated Biphenyls (PCBs) Congeners	EPA-CRL-8081
33. Dioxins	EPA-SW846-8290 and 1630
34. Leachate Quality Test	Myers and Brannon 1988
35. Surface Runoff Quality	Skogerboe et al. 1987

Notes: * Metals = arsenic, cadmium, chromium, copper, lead, mercury, silver, nickel, and zinc; Use EPA 1986 Method 245.6 for mercury determinations.

Methods:
ASA = American Society of Agronomy/Soil Science Society of America (Page, Miller, and Keeney 1982 and 1996).
CSSS = Canadian Society of Soil Science (Carter 1993).
ASTM = American Society for Testing and Materials (ASTM 1996).
EPA = USEPA (1986).

Table 3
Appropriate Tests for Biological Properties of Dredged Material to Determine Suitability for Beneficial Uses

Analysis	Methods
36. Manufactured Soil Test	Sturgis et al. (1999)
37. Plant Bioassay	Folsom, Lee, and Preston 1981
38. Animal Bioassay	ASTM 1998, Standard Guide E 1676-97
39. Elutriate Bioassay	EPA 1991 (Method: 11.1.4) (USACE/USEPA 1991)
40. Pathogens (coliforms)	Standard Methods: 9221 E (Greensberg et al. 1992)

CHARACTERIZATION TESTS USEFUL IN DETERMINING PHYSICAL PROPERTIES

Grain Size, Particle Shape, and Texture. Grain size and particle shape are useful in determining the stability, resistance to shear, permeability, compressibility, and compactability of the dredged material. Grain size can be determined mechanically with sieves (direct) or indirectly with the hydrometer or pipette methods. Sieving is not practical for silt- or clay-sized particles since they tend to clog the screen. When conducting grain-size determinations on silt- or clay-sized particles, sedimentation in water (hydrometer or pipette methods) is preferred. Grain-size distribution and particle shape significantly impact on the weight-bearing capacity of soil or dredged material. Angular particles tend to interlock, forming a stable dense mass capable of bearing more weight than rounded particles, which tend to slide or roll past each other. Dense soils have greater weight-bearing capacities than loose soils. The strain required to reach failure is approximately twice as large for angular-shaped particles as that required to reach failure for spherical particles.

The texture of a soil is its appearance or “feel” and depends on the relative size and shape of the particles, as well as the range or distribution of those sizes. Soil texture is affected by the mineral content, organic matter, soil aggregates, and moisture present in the soil. Soil texture contributes to the water-storage capacity, water-infiltration rates, aeration, fertility, and ease of tilling, as well as compressibility. The texture of dredged material can limit its beneficial uses. For example, predominantly sandy dredged material can be used as a fill material or in dike construction, but might not be suitable for vegetation establishment because of its low nutrient content and water-holding capacity.

Water Content and Permeability. Water content and permeability are interrelated and have a significant influence on the suitability of a dredged material for use as a fill, subgrade, or foundation material. Water content (w) is one of the most important factors affecting the properties and behavior of dredged material. Water content is the ratio of the weight of water to the dry weight of the solids in a mass of dredged material, expressed as a percentage. Soil must be compacted to obtain the required strength and density while the water content is maintained at the optimum level during construction projects (e.g., embankments, highway subgrades). The behavior of fine-grained soils, like silt or clay, is influenced by the water content.

Permeability is one of the factors that determine shear strength and is a measure of water or air movement through the dredged material. Permeability is determined by mineralogical composition, particle size and distribution, void ratio, degree of saturation, and pore fluid characteristics. Very fine-grained materials (clayey) generally have low permeability rates to water, and this is a desirable feature when dredged material is used as fill or foundation material in landfills. However, if the material is to be used for revegetation projects, coarse-grained material would need to be added to clayey material to enhance aeration and root penetration.

Atterberg Limits (Plasticity Tests). Plasticity tests are conducted on dredged material that is finer than 0.425 mm to determine the range of water content in which plasticity is exhibited. The types and amounts of clay particles present and water content, as well as the physicochemical interactions of clay particles, determine the plastic behavior of a dredged material. The Atterberg Limits consist of the liquid limit (LL) and plastic limit (PL) and can be used to assess the amount of dewatering needed before a dredged material can be handled and processed. The Atterberg

Limits, either individually or with other soil properties, can be correlated to other properties such as compactability, compressibility, shear strength, or permeability. The water content above which a dredged material is in a semiliquid state is its LL. The water content that is the lower limit of the plastic state and the upper limit of the semisolid state is the PL. If the water content of the dredged material is below its PL, it becomes brittle and breaks into fragments when remolding is attempted.

The plasticity index (PI), liquidity index (LI), and activity index (AI) are derived from the PL and LL. The PI is the difference between the LL and PL. Materials with a large PI have more plasticity than those with a smaller PI. The PI is directly proportional to the clay content. The LI is some dimensionless number that indicates the ratio of the water content w of a cohesive soil minus the ratio of its PL to the PI ($LI = w - PL/PI$), and it normalizes the water content relative to the plasticity index. The following relationships are noted for remolded soil: (a) when the LI = 0, the soil is at its PL water content and is stiff, (b) when LI = 1.00, the soil is at the LL water content and is soft, and (c) when LI > 1.00, the soil is liquidlike (slurry). The AI is the ratio of the PI to the percentage of clay and is useful in identifying the type of clay minerals present in the dredged material: AI = 0.3-0.5 for kaolinite, AI = 0.5-1.0 for illite, and AI = 1-7 for montmorillonite. Each clay mineral has a unique behavior. Knowledge of the clay mineral type aids in determining the behavior and water-holding capacity of the dredged material.

Organic Content/Organic Matter. The organic content in a soil can contribute to high plasticity, high shrinkage, high compressibility, permeability, or low strength. Soils with significant amounts of organic matter generally have lower shear strength and higher compressibility than those composed mainly of inorganic minerals. An organic soil is one where the LL of the oven-dried soil is <75 percent of the LL of the soil before it was dried. While a certain amount of organic material can be desirable (e.g., enhanced buffering capacity, immobilizing contaminants), it can make characterization of dredged material more difficult since there are many forms of organic materials, and, depending on the origin, each has distinctive attributes.

CHARACTERIZATION TESTS USEFUL IN DETERMINING ENGINEERING PROPERTIES

Compaction Tests. One of the basic and least expensive construction procedures used for soil stabilization is compaction. Compaction mechanically increases the amount of solids per unit volume of soil. It improves the engineering properties of foundation material so that the required shear strength, structure, or void ratio are obtained, while decreasing the shrinkage, permeability, and compressibility. Compaction is often required when building subgrades or bases for airport pavements, roads, embankments, earthfill dams, or similar structures. The Proctor and California Bearing Ratio (CBR) are two commonly used compaction tests. Three basic Proctor (compaction) tests are used depending on the amount of compaction anticipated: the standard, the modified, and the 15-blow compaction tests. The standard compaction test is generally used in routine foundation and embankment design to simulate field compaction; the modified compaction test is used when a higher level of compaction is desired; and the 15-blow compaction test is used when lower levels of compaction are required. These tests aid in determining the percent compaction and water content necessary to obtain the desired engineering properties for construction. Before a dredged material is used as a fill for road bases, foundation pads, or embankments, it is vital that the amount of compaction needed to obtain the required shear strength, compressibility, and permeability is determined.

The CBR is used to determine resistance to penetration of a material (subgrades or bases) before its ultimate shearing modulus is reached. Its primary use has been in the design of flexible pavements for airfields located in areas where frost action is not a controlling factor. Since moisture content affects the results, tests must be conducted using a moisture content that approximates the moisture content anticipated at the site where the pavement is to be constructed. Values obtained usually range from 3 to 80 depending on the type of material tested.

Consolidation Tests. Consolidation tests are needed to estimate the readjustment or plastic deformation likely to occur when soil is subjected to increasing pressures or loads and to determine the compressibility of the dredged material (compressibility index C_c). It is a rate process based on the time required for pore fluid, either water or air, to flow out of soil pores (void-ratio reduction). The rate of consolidation is dependent on (a) the degree of saturation, (b) the coefficient of soil permeability, (c) the nature of pore fluid (air or water), and (d) the distance the pore fluid has to travel for equilibrium to occur. The amount of consolidation or settlement likely to occur must be determined before dredged material is used as a base or subgrade.

Shear Strength. The behavior of dredged material under a load is a measure of its shear strength. Before a dredged material can be used for construction purposes, its shear strength must be determined (e.g., weight-bearing capacity and stability of earthen slopes are directly related to shear strength). Three tests are generally used to determine shear strength: (a) the unconsolidated, undrained (UU) test, (b) the consolidated, undrained (CU) test, and (c) the consolidated, drained (CD) test. The methods and appropriate characterization tests for determination of geotechnical and engineering properties of dredged material are listed in Table 1.

CHARACTERIZATION TESTS USEFUL IN DETERMINING CHEMICAL PROPERTIES

pH. The chemical properties of dredged material are interrelated, but pH is one of the most useful and informative parameters in characterizing those properties. It is a measure of the concentration and activity of ionized hydrogen (H^+) in the dredged material/soil solution. The pH affects the chemical properties of dredged material, including (a) surface charge of organic matter, clay, or mineral particles, (b) solubility, mobility, and toxicity of contaminants (e.g., metals, organics), (c) relative binding of positively charged ions to the cation exchange sites, (d) calcium carbonate equivalents (liming requirements), and (e) nutrient availability. pH values are “beacons” that point to potential corrective actions: pH < 4.0 is indicative of the presence of free acids (e.g., sulfates or nitrates); pH < 5.5 indicates that toxic amounts of exchangeable aluminum, iron, or manganese may be present; pH values between 7.8 and 8.2 are indicative of large accumulations of bicarbonate ions. pH is a useful tool for determining the kinds of analyses or corrective action(s) needed before dredged material can be used in beneficial ways.

Calcium Carbonate Equivalent. The calcium carbonate equivalents (lime requirements) and pH are closely related parameters. The calcium carbonate equivalent is an indicator of the amount of lime required to neutralize any acidity present in order to maintain the desired pH. If large concentrations of sulfides are present in the dredged material, heavy lime application may be required to neutralize the acidity produced from the oxidation of sulfides to sulfates. The need for lime can usually be determined by the calcium carbonate equivalent, which is expressed in terms of lime ($CaCO_3$/100 g of dredged material). Agricultural lime is the most commonly used basic material because of its low cost and growth-enhancing qualities. Liming can reduce the bioavailability and toxicity often present in acidic soil when aluminum (Al), manganese (Mn), and other metals (zinc (Zn), copper (Cu), or nickel (Ni)) are present at elevated concentrations.

Cation Exchange Capacity (CEC). Cation exchange reactions in a soil are important because they alter soil physical properties, cause/correct acidity and basicity, affect soil fertility, and can purify or alter percolating waters. Electrostatic charges are inherent on soil particles. Some charges are permanent, while others are pH dependent. Exchangeable cations (positively charged ions) are attracted to the negatively charged surfaces and replace the cations on the particle surfaces. As the CEC increases, the amount of adsorbed cations increases. The CEC is pH dependent and directly proportional to the clay concentration, organic matter content, and particle-size distribution.

Salinity. Salinity is a measure of the concentration of soluble salts. Cations (sodium, potassium, calcium, and magnesium) and anions (sulfates and chlorides) are the predominant solutes that contribute to salinity. Salt accumulations in soil can adversely affect its structure (decreases the cohesiveness of particles), inhibit water and air movement, increase the osmotic potential, decrease the available nutrient content, induce toxicity to specific ions, and prevent the growth of many plants (except halophytes). Salinity is conventionally measured on aqueous extracts of a saturated paste. A saturated paste is prepared by adding just enough water to saturate the soil sample until it glistens and flows slightly when the container is tipped. The recommended ratio of soil:water in the paste is the smallest amount that can be easily removed with vacuum or pressure since this amount readily correlates to water content under field conditions. Other extraction ratios (1:1, 1:5, etc.) can be used but are not readily correlated to water content under field conditions. The method utilized should be based on the specific conditions and needs of the project. Vegetative responses to salt-affected soil are also influenced by the ratio of calcium to the other ions in solution. Yields are generally reduced when the ratio of calcium to other ions is less than 0.10 (the critical calcium ratio).

Sodium Adsorption Ratio (SAR). The SAR indicates the tendency for sodium to adsorb to the cation exchange sites at greater concentration than calcium or magnesium and is an index of the relative sodium content of the soil solution expressed in mmol l^{-1}. More specifically, it is the ratio of sodium ions to the sum of the calcium and magnesium ions ($SAR = (Na^{+})/(Ca^{2+} + Mg^{2+})^{0.5}$). Dredged materials with SAR values in the range of 10-13 or higher are generally considered sodic. The concentration of exchangeable sodium in a sodic soil is so high that the soil becomes dispersed and impermeable to water as the pores become clogged with dispersed or dislodged clay particles. Plant growth is adversely affected when sodium occupies a high proportion of the exchange sites because pH can become basic (8.5 to 10.5), and the soil aggregates required for plant growth disintegrate and disperse.

Electrical Conductivity. Electrical conductivity is another measure of the soluble salts (ionic strength) present in the dredged material/soil and is reported in decisiemens per meter (dS m^{-1}). It increases as the concentration of dissolved salts increases (electrical conductivity (dS m^{-1}) $\times$ 10 = mmol L^{-1} of soluble salts (total cations or anions)). The electrical conductivity is usually measured on a saturated paste extract of the dredged material using electrodes, and the value obtained can be related to the actual soluble salt concentration in the dredged material. Generally, plants respond in the following ways to electrical conductivity: <2, negligible; 2-4, slight reduction in yield of sensitive plants; 4-8, reduced yield in most plants; 8-16, satisfactory yield only in salt-tolerant plants; and >16, satisfactory yield only in plants that are extremely salt-tolerant. The information from salinity and electrical conductivity tests are somewhat similar but used for different purposes by different individuals. Either test can be used to meet the specific needs of the user.

Total Organic Carbon. Soil organic carbon is the fraction of total carbon that is derived from the organic matter in the soil and consists of plant, animal, and microbial residues (fresh and in all stages of decomposition) as well as the humus. Organic matter normally contains many of the nutrients required for plant growth: 95 percent of the dredged material nitrogen, 50 percent of the phosphorus, and when iron sulfides are not present, ≥80 percent of the sulfur. Organic carbon comprises 48-58 percent of the organic matter content of soil. Conversion factors can be used to obtain an estimate of the organic carbon (organic matter × 1.724 (surface soils) or 2.0 (subsurface soils)).

Total Phosphorus/Orthophosphorus. Phosphorus is an essential nutrient for all forms of life. Plants take it up primarily as the orthophosphate ion ($H_2PO_4^-$) from fertilizers or as it is released from organic matter decomposition. The other ionic forms, monophosphate ions (HPO_4^{2-}) or phosphate ions (PO_4^{3-}), are less available for plant uptake. Most metal phosphates are insoluble under neutral and alkaline conditions (except those of alkali metals) but are soluble under acidic conditions. The orthophosphate ion ($H_2PO_4^-$) is generally the soluble form of phosphorus occurring in dredged material/soils, but it can react quite rapidly with soluble iron or aluminum to form insoluble phosphates. pH affects phosphorus availability through its effect(s) on microbial growth and the solubility of calcium, iron, or aluminum. The optimum pH for phosphorus bioavailability to plants is 6.5 in mineral soils and 5.5 in organic soils.

Carbon:Nitrogen (C:N) Ratio. The C:N ratios present in dredged material/soil help determine if conditions are optimal for the growth of soil microbes, as well as plants. Bacteria require four pounds of carbon for every pound of nitrogen (4:1) in order to have optimum growth and metabolism (decomposition/recycling of organic matter). Decompositional activities of microbes can be increased by the addition of more nitrogen. Materials with a wide C:N ratio are low in nitrogen content. Bacteria are more abundant and in closer contact with soil particles than the root surfaces of plants. Therefore, if nitrogen is low, bacteria will use up available supplies before it ever becomes accessible to plant roots, resulting in nitrogen deficiency in plants.

Nitrogen. Nitrogen is the nutrient most likely to be limiting for plant growth. It can be lost from soil/dredged material by leaching, volatilization, denitrification, or immobilization. Ammonium nitrate is often used as a fertilizer because of its low cost. Half of its nitrogen content is in the form of ammonium and half is nitrate. The nitrate ions are quite mobile and bioavailable to plants when ammonium nitrate is added to soil. The ammonium cations tend to adsorb to the cation exchange sites and are bioavailable to plants but less mobile than the nitrate.

Potassium. The availability of potassium in the dredged material needs to be determined if vegetation establishment is the potential beneficial use. Most of the potassium requirements of vegetation is supplied by the exchangeable potassium ions in the soil CEC and from soluble potassium ions in the soil solution. If the CEC of the dredged material is low, as in sandy material, it may need to be amended with potassium fertilizers. Since potassium forms a positive ion, it has limited mobility through the soil and should be placed where it is most accessible for growing roots.

Sulfur. Sulfur is generally taken up by plants in the form of sulfates and is often supplied from the decomposition of organic matter or soluble minerals. Although sulfur-deficient soils are not very common, sulfur is a necessary constituent of three essential amino acids. The amount of sulfur required is dependent on the target vegetation.

Contaminants. The presence of contaminants (metals, pesticides, PAHs, PCBs) in dredged material is a concern. These substances generally sorb to the sediment particulates (i.e., organic matter, clay particles, aggregates, hydrous oxides) and settle out in the anaerobic (reduced) alkaline environment existing on the bottom of waterways. The solubility, mobility, and bioavailability of these contaminants are generally reduced under anaerobic alkaline conditions. However, the dredged material can become oxidized and more acidic during dredging and placement into CPFs. The potential then exists for sorbed contaminants to become solubilized, mobile, and bioavailable. Analyses need to be conducted to determine if contaminants have become solubilized and bioavailable (i.e., DTPA, biological screening tests). Then the appropriate corrective measures can be taken to prevent adverse environmental impacts.

Surface Runoff Quality and Leachate Quality Tests. The potential exists for solubilized contaminants in the dredged material to migrate offsite during and after placement into upland sites. As the dredged material dries out and becomes oxidized, the potential exists for contaminants to become soluble, mobile, and bioavailable. During precipitation events, water percolates through the dredged material, and contaminants can migrate in the runoff and be carried into surface-receiving waters. Chemical analyses are conducted on surface runoff waters when there is concern about contaminants that have established water quality criteria (WQC), and/or a biological evaluation is conducted for those contaminants that have no established WQC. The leachate quality test is used when the potential exists for contaminants to enter surface-receiving waters or groundwaters. The leachate quality test evaluates the potential for adverse impacts from (a) seepage from dikes into a receiving water body, (b) subsurface drainage into an aquifer used for drinking water, and (c) seepage into nonpotable subsurface water. The results of both tests should be compared with the quality of an appropriate reference surface water or groundwater source. Methods and appropriate characterization tests for determining chemical properties are listed in Table 2.

CHARACTERIZATION TESTS USEFUL IN DETERMINING BIOLOGICAL PROPERTIES: Biological tests are conducted to assess the potential for adverse effects to occur in biological indicator organisms as a result of exposure to contaminants in the dredged material. These tests integrate existing conditions in the dredged material and evaluate the bioavailability of contaminants in the dredged material. The chemical species (form) of contaminants determine their bioavailability and potential for uptake, bioaccumulation, and toxicity once they reach their site of action in living organisms, not simply their presence in dredged material. Elutriate bioassays are conducted to assess/evaluate the bioavailability and potential toxicity of contaminants that are either adsorbed on particle surfaces (can be easily washed off or eluted) or solubilized in pore waters. The manufactured soil test and plant/animal bioassay are designed to determine if adverse (toxicity) effects occur in test organisms as a result of exposure to contaminants in the dredged material. The responses of dicot and monocot plant species are evaluated during the plant bioassay, and the optimum combination of dredged material, carbon source, and organic waste amendments is assessed using the manufactured soil test. Test conditions can be controlled or varied to simulate those expected to be encountered under field situations (upland or wetland) so that the data obtained can be used to make realistic predictions and evaluations. The pathogen (coliform) analysis is used to detect the presence of disease-causing bacteria, usually of fecal origin. Table 3 lists methods and appropriate characterization tests for determining biological properties.

BENEFICIAL USES OF DREDGED MATERIAL: There are many potential beneficial uses of processed dredged material in upland, wetland, or aquatic environments (see Table 4). The properties, as well as the types and bioavailability of contaminants, will determine the beneficial uses of a dredged material and the amount of processing needed to reduce adverse environmental impacts. In addition, waste materials such as fly ash, alkaline wastes, and spent lime can be added to dredged material to engineer a soil product that can meet specifications required for a particular beneficial use. Examples are impermeable caps for landfills, superfund sites, and brownfields.

Table 4
Potential Beneficial Uses of Dredged Material

Upland Environments
Fill, subgrade construction:
Highway/road/airport landing strip
Asphalt, concrete, bricks
Washouts/barren areas along highways
Mine shaft fill
Covers for landfills, brownfield, superfund and mining sites
Earthen slopes
Biomechanical erosion control structures
Cemeteries
Manufactured soil products:
Landscaping
Bagged soil
Recreational areas/parks/campgrounds
Silviculture, horticulture, agriculture
Covers for landfills, brownfield, superfund and mining sites
Wetland Environments
Constructed wetlands for water quality improvement
Creation of mitigation, wildlife habitat wetlands, marshes, etc.
Erosion control, bank stabilization
Geotextile tube fill, berm construction
Biofilters for landfill leachate/seepage
Biofilters for acid mine drainage
Aquatic Environments
Capping open-water placement sites
Beach and shoreline nourishment
Solid structures for fish habitat
Geotextile tube fill
Creation of:
Islands
Tidal flats
Sea grass meadows
Oyster beds
Fishing reefs
Clam flats
Dike or berm construction

While habitats will develop from placement of dredged material into disposal sites, the enhancement and development of high-quality habitats require the utilization of sound management strategies.

Dredged material is an under utilized resource that can be used in a beneficial manner once appropriate physical, engineering, chemical, or biological properties are determined. Over 2,000 man-made islands have been created in the Great Lakes and coastal and riverine areas by the U.S. Army Corps of Engineers. These islands, along with additional ones, can provide nesting areas, protection from terrestrial predators, and the seclusion from humans needed by migratory or colonial nesting waterbirds and threatened or endangered species (e.g., pelicans, spoonbills, gulls, herons, terns). Additional beneficial uses in aquatic environments include habitat creation (reefs, tidal flats, sea grass meadows), erosion control (underwater berms made of geotextile tubes filled with dredged material, beach and shoreline nourishment), and construction (dikes). Dredged material can be used to augment decreasing wetland resources including freshwater and saltwater marshes, biofilters for landfill leachate, constructed wetlands for wastewater treatment, or fill for sloughs in riverine areas or denuded reservoir banks. There are a vast number of beneficial uses in upland areas including construction of roads or airport runways, landscaping (manufactured soil products), parks and recreational area development, cemetery development, and others. All products made from dredged material will have to meet the performance specifications established for existing material and will have to be cost competitive, available in a timely manner, and tested for performance.

A phased approach to testing should be employed in determining suitability for beneficial uses. It may not be necessary to conduct all of the characterization tests. An evaluation procedure for beneficial uses of dredged material is shown in Flowcharts 3-1 and 3-4 of the USACE/USEPA Technical Framework (USACE/USEPA 1992). First, the beneficial use needs and/or opportunities should be determined for the specific location. Next, an evaluation of the physical suitability of material for the proposed uses needs to be conducted using appropriate characterization tests for determining the physical and engineering properties in Table 1. If the physical properties do not meet desired specifications, processing the dredged material by addition of available materials such as spent lime, fly ash, or kiln dust should be considered. Many times the dredged material can be conditioned to meet desired specifications. Next, the logistical and management requirements are considered. The evaluation of environmental suitability is then considered. If there is reason to believe the dredged material is contaminated, either the chemical or biological or both characterization tests should be conducted. A modified version of the framework for testing and evaluating for beneficial use applications is presented in Figure 1. If the results of the chemical/biological screening tests indicate the potential for adverse impacts, the dredged material should be treated and then retested for adverse impacts. If adverse impacts are no longer indicated, or if there is no reason to believe the dredged material is contaminated, the beneficial uses can be realized, and the evaluation of socioeconomic, technical, management, and other environmental considerations, either as an Environmental Assessment or an Environmental Impact Statement, is conducted as shown in Flowchart 3-1 of the USACE/USEPA (1992) technical framework. If adverse impacts are still indicated, the dredged material should not be used for beneficial purposes.

SUMMARY: Dredged material can be a valuable resource with numerous potential beneficial uses. Although dredged material is analyzed prior to placement into CPFs, many physical, chemical, and biological processes can continue to occur depending on the prevailing environmental conditions (e.g., precipitation, temperature, biogeochemical factors) around the CPP. The results obtained

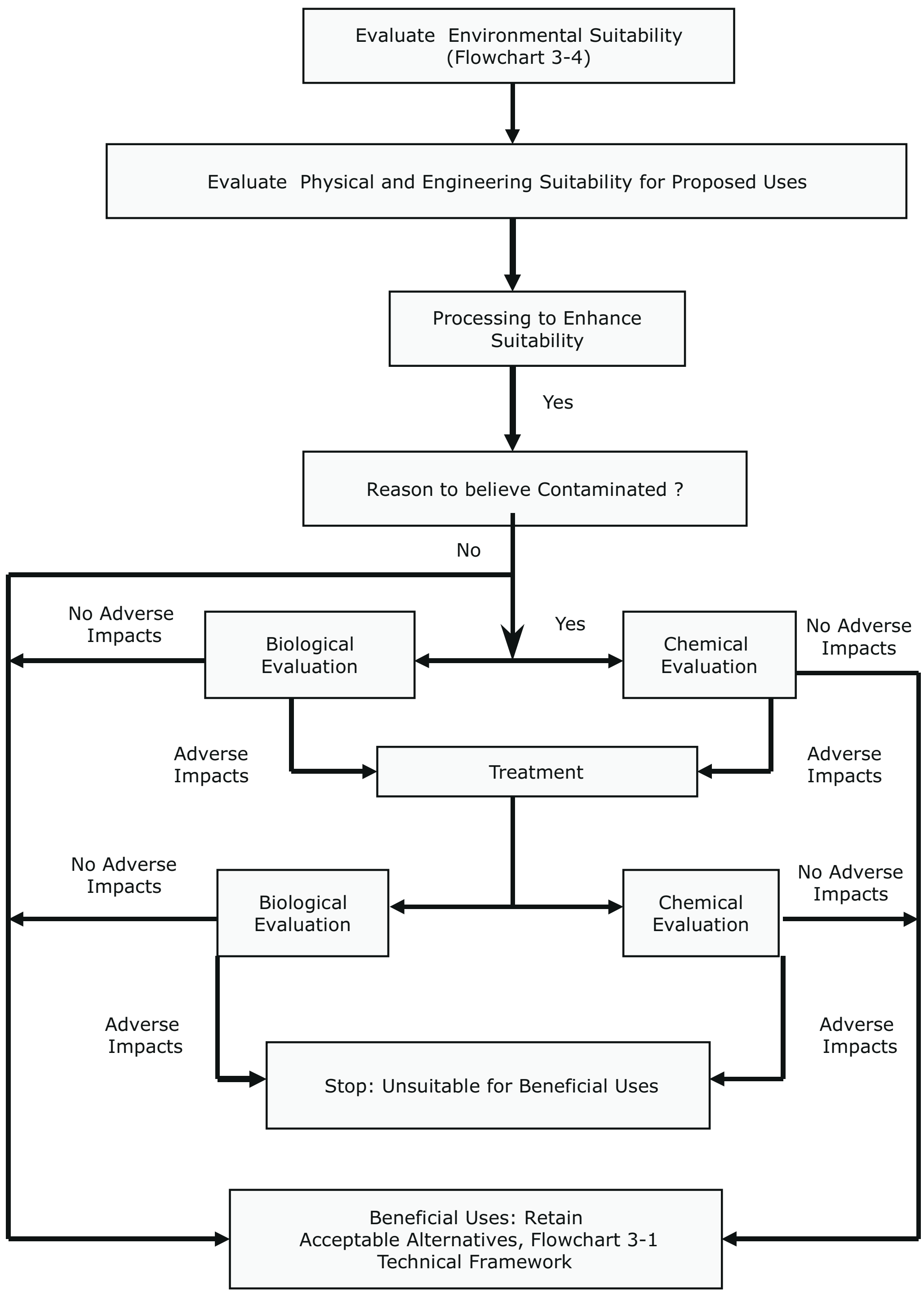

Figure 1. Framework for testing and evaluation for beneficial uses

from the appropriate characterization tests will provide information useful in determining the current physical, engineering, chemical, and biological properties of the dredged material. Knowledge of the properties and the limitations (e.g., contaminant bioavailability) of the dredged material will aid in determining the alternatives for beneficial uses.

POINTS OF CONTACT: For additional information, contact the authors, Linda E. Winfield (601-634-3836, *winfiel@wes.army.mil)* and Dr. Charles R. (Dick) Lee (601-634-3585, *leec@wes.army.mil)* or the managers of the Dredging Operations Environmental Research Program, Mr. E. Clark McNair (601-634-2070, *mcnairc@mail.wes.army.mil)* and Dr. Robert M. Engler (601-634-3624, *englerr@wes.army.mil)*. This technical note should be cited as follows:

Winfield, L. E., and Lee, C. R. (1999). "Dredged material characterization tests for beneficial use suitability," *DOER Technical Notes Collection* (TN DOER-C2), U.S. Army Engineer Research and Development Center, Vicksburg, MS**.**
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