

Case Studies: Characterization Tests to Determine Dredged Material Suitability for Beneficial Uses

PURPOSE: This technical note describes the application of appropriate physical, engineering, chemical, and biological tests described in Technical Note DOER-C2 (Winfield and Lee 1999) for characterizing and determining the potential for beneficial uses of dredged material in aquatic, wetland, and/or upland environments.

BACKGROUND: The U.S. Army Corps of Engineers (USACE) maintains and improves navigable waterways by dredging approximately 400 million cu yd of sediment from these waterways each year. Contaminated sediments, unacceptable for open water placement, are usually placed in confined placement facilities (CPFs). Many existing CPFs are filled to capacity. Finding additional suitable CPFs for dredged material is a growing concern. Alternatives must be developed to provide beneficial uses for both the contaminated and noncontaminated dredged material in existing CPFs so that these materials can be removed and used periodically, resulting in the creation of additional CPF storage capacity. Characterization tests have been described in Technical Note DOER-C2 (Winfield and Lee 1999) that can assist in the evaluation of the suitability of a dredged material for beneficial uses. These characterization tests were applied to specific dredged materials to determine the appropriateness of the tests and the actual implementation of the beneficial use evaluated. This technical note describes the application of these tests to dredged material collected from Mobile, AL, and Toledo, OH, CPFs and a sediment collected from New York/New Jersey (NY/NJ) Harbor.

INTRODUCTION: The characterization and testing of a dredged material must be matched to a particular beneficial use. A number of physical, engineering, chemical, and biological tests have been described in Technical Note DOER-C2 (Winfield and Lee 1999) to characterize and aid in making decisions about the potential beneficial reuse of the dredged material. Appropriate characterization tests are listed in Tables 1 through 3. Normally, a sediment is tested and evaluated according to the USACE/U.S. Environmental Protection Agency (USEPA) (1992) prior to dredging and disposal. Those data can be used in the initial evaluation of potential beneficial uses of the dredged material, indicating, for example, the presence of contaminants. However, the placement of dredged material in a CPF and the physicochemical changes occurring in the dredged material can result in changes in relation to the nature and location of contaminants within the CPF. Normally, contaminants when present in the dredged material tend to be associated with the finer grain sized particles. Even though most of the tests identified in Tables 1 and 2 were initially designed for soils, they can be applied to dredged material because of its soil-like nature.

Examples of beneficial uses of dredged material are listed in Table 4. The beneficial use selected for a specific location should be evaluated using appropriate characterization tests. Only those tests that are required for determining the suitability of dredged material for a beneficial use should be conducted.

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

DTIC QUALITY INSPECTED 4

19990730 018

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 Hydrometer Test Pipette Test	ASTM D422-63; COE V; DOD 2-III, 2-V, 2-VI; CSSS 47.4 ASTM D422-63; CSSS 47.3; COE V 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 Standard Compaction Test Modified Compaction Test 15 Blow Compaction Test California Bearing Ratio	COE VI ASTM D698-91 ASTM D1557-91 ASTM D5080-93 DOD 2-IX
8. Consolidation Tests	COE VIII; ASTM D2435-90
9. Shear Strength UU (unconsolidated, undrained) CU (consolidated, undrained) CD (consolidated, drained)	COE X-18 COE X-29 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.	

There are two approaches for the application of characterization tests to determine the potential beneficial uses of dredged material:

- Beneficial Use Suitability Testing.
- Beneficial Use Selection Testing.

If a specific beneficial use can be selected initially, then those tests that provide the information required to make a decision on the acceptability of the processed dredged material for that beneficial use should be conducted (Beneficial Use Suitability Testing). If no specific beneficial use is selected

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 and Lee (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)

**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

initially, then more of the characterization tests listed in Tables 1 through 3 should be conducted to determine the suitability for a wider range of beneficial uses (Beneficial Use Selection Testing). Case studies of the use of appropriate characterization tests will be discussed to illustrate the decision process.

Two examples will be discussed that relate to dredged material with low levels of contaminants in CPFs. The decision process is fairly straight forward. Sometimes a beneficial use will have a specification that must be met, such as permeability for a landfill cap. The physical nature of the dredged material by itself may not meet that specification. However, the processing of the dredged material by the addition of an available waste material such as flyash or spent lime could result in meeting the required specification.

The third example relates to a moderately contaminated dredged material and is more complex. Under these conditions, characterization testing was conducted in phases. The results of the initial tests determined the need for further testing.

SPECIFIC CASES SELECTED FOR APPLICATION OF APPROPRIATE CHARACTERIZATION TESTS:

Mobile, AL. Landfill cover was the beneficial use selected for dredged material in two CPFs, North and South Blakeley. Two landfill cover uses were identified. A landfill impermeable cap was required to accomplish final closure of the 70-acre landfill of the City of Mobile. In addition, a vegetative cover material was required for placement on the impermeable cap. Local requirements and specifications were considered and matched up with the characterization tests listed in Tables 1 through 3. Initially, a bulk analysis of the dredged material in the CPF was conducted.

These data indicated a relatively low level of contamination for metals, petroleum aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and dioxins. These data were reviewed by appropriate state and local regulatory agencies and deemed acceptable for landfill cap use. Characterization tests performed on the dredged material for landfill impermeable cap were physical grain size, compaction, pH, and organic matter. A required specification for the cap of 10^{-5} cm/sec permeability had to be met with a minimum of sand in the cap material. Dredged material from that portion of the CPF that contained predominately fine textured material with a minimum of sand was used. Characterization tests for compaction (No. 7, Table 1) and permeability (No. 4, Table 1) were conducted on dredged material alone and in combination with different amounts and types of locally available ash (Table 5). Addition of flyash to dredged material has been used to decrease permeability of the dredged material when used as capping material.

Table 5 Permeability (cm/sec) Measured in Compaction Tests, Soil pH, Grain Size, and Organic Matter Test Results for South Blakeley CPF Dredged Material									
Test Conducted	Dredged Material	Dredged Material Plus Ash							
		Source A Ash				Source B Ash			
		10%	20%	30%	40%	10%	20%	30%	40%
Soil compaction/Permeability	10^{-6}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-7}	10^{-8}	10^{-7}	10^{-7}
Soil pH	6.9	7.5	8.0	8.5	8.5	7.7	8.5	8.5	8.5
Grain size									
Sand (%)	10								
Silt (%)	50								
Clay (%)	40								
Organic matter	1.5								

Grain size (No.1, Table 1) and percent organic matter (No. 6, Table 1) were also conducted on the dredged material. Since flyash was being added to the dredged material, the pH (Test 10, Table 2) of the resulting blends was determined. Because the silty clay dredged material provided a permeability of 10^{-6} cm/sec without the addition of ash, the dredged material alone would be suitable

to meet the required specifications. Addition of ash decreased the permeability and increased soil pH. A compacted cap made from dredged material with ash at a pH of ~8 would be suitable as a bio-barrier against plant root penetration, if this were a concern. However, root penetration for this landfill cap was not a concern. The presence of 1.5 percent organic matter in the dredged material did not adversely affect the compaction or permeability of the dredged material. Therefore, the dredged material alone without ash addition was selected for the cap.

The vegetative cover for the landfill was evaluated using the manufactured soil screening test (No. 36, Table 3). Initially, dredged material from both North and South Blakeley CPFs were tested for their potential for manufacturing topsoil (Technical Note DOER-C6, Sturgis and Lee 1999). Available cellulose and biosolids were used in combination with dredged material from the CPFs. Two cellulose materials were used, Source A waste paper fiber and Source B waste paper fiber. One source of biosolids was available. Based on these tests results, a manufactured soil containing North Blakeley dredged material, Source A waste fiber cellulose, and biosolids produced a suitable topsoil for landfill vegetative cover. The South Blakeley CPF dredged material, Source A waste fiber cellulose, and biosolids produced a less vigorous vegetative cover. Further characterization tests (salinity, No. 13, Table 2; and pesticides, No. 30, Table 2) were performed to determine the reasons for the poorer growth in the South Blakeley CPF dredged material blends. Since South Blakeley CPF received dredged material closer to Mobile Bay, salinity was considered a possible reason for the poorer vegetative growth. The Source A waste fiber cellulose was a product of a washing process that used sodium bicarbonate as an ingredient. The added salinity in the waste fiber may have resulted in the poorer growth of vegetation observed in the manufactured soil screening test when the percentage of waste fiber was increased in the blend. In addition, the watershed draining into the Mobile river and bay is predominately agricultural. It is possible, therefore, that the presence of agricultural pesticides/herbicides in the dredged material may have contributed to the poorer vegetative growth. Salinity was measured at 11 parts per thousand in the blended manufactured soil, while near or below detection limits of pesticides/herbicides were observed. Rinsing the blends with water resulted in reduction of salinity to below two parts per thousand and improved vegetative growth for both North and South Blakeley CPFs dredged material blends. Additional characterization tests (No. 29, 31, 32, 33, Table 2) were conducted on both the dredged material and the selected blend of manufactured soil to more fully document the contaminant content of the final product for the information and approval of the local regulatory agencies. The project has been initiated and will be complete within 18 months.

Toledo, OH. The beneficial use selected for Toledo Harbor CPF, Cell 1 was manufactured topsoil. Characterization tests (No. 26, 27, 28, 29, Table 2) were conducted to analyze dredged material at different depths in the CPF and indicate any variations in contaminants present. Concentrations of metals, PAHs, PCBs, and pesticides were observed to be relatively low. Manufactured soil screening tests (No. 36, Table 3) indicated that a fertile topsoil could be blended from dredged material, yard waste, and biosolids (Lee et al. 1998). Additional characterization tests (No. 1 and 6, Table 1; and No. 10, 11, 12, 14, 20, 24, 25, 26, 27, 29, 30, 31, and 32, Table 2) were conducted to characterize the dredged material and blends of manufactured topsoil. The results of the characterization tests were presented to local regulatory agencies for their review, comments, and approval for the commercialization of manufactured soil products from the Toledo Harbor CPF. Metal concentrations in the manufactured soil were evaluated in relationship to the USEPA 503 regulations for acceptable

maximum metal concentrations in agricultural soils receiving biosolid applications. Consensus was achieved and commercialization plans have been initiated in Toledo, OH.

New York/New Jersey Harbor. This example illustrates the application of characterization tests to specific beneficial uses for dredged material collected from the waterway prior to placement in a CPF. An extensive evaluation of disposal alternatives was conducted for the U.S. Army Engineer District, New York, according to the USACE/USEPA (1992). Included in the evaluation was the potential for beneficial reuse of the dredged material. Two specific beneficial uses, employing innovative technologies, were selected for NY/NJ Harbor dredged material: Manufactured artificial soil and high-pressure pozzolaic construction blocks. Because of concerns for the presence of contaminants in the dredged material, a phased approach to characterization testing was performed.

- **Manufactured soil.** Characterization tests (No. 1, 3, 5, and 6 in Table 1; No. 13, 18, 29, 30, 31, 32, and 33 in Table 2; and No. 36 in Table 3) were conducted on the dredged material in the initial phase of testing. The dredged material was a silty clay fine-grained material, resembling black mayonnaise, that contained elevated concentrations of metals, PAHs, PCBs, and dioxins. The source of cellulose used in the initial manufactured soil screening test was sawdust and the source of biosolids was BIONSOIL^R, derived from dairy cow manure. Grass grew in a blend of dredged material, cellulose, and biosolids that contained reduced salinity and contaminants compared to the unamended dredged material. The other plant species used in the manufactured soil screening test (tomato, marigold, and vinca) did not grow well in the blend that showed grass growth. Salinity was measured at 11 parts per thousand and thought to be the factor affecting the growth of tomato, marigold, and vinca. The concentrations of contaminants in the manufactured soil were reduced during the blending through dilution to approximately one-third of their original concentration. Even though contaminants were present in the manufactured soil, grass grew and plant tissues contained low levels of contaminants. For the next phase of testing, an additional characterization test, the earthworm bioassay (No. 38, Table 3), was conducted to evaluate the bioavailability of these contaminants in the manufactured soil to earthworms exposed to the blend. The results of the earthworm bioassay indicated that earthworms did contain some metals such as copper, zinc, cadmium, lead, and nickel and low levels of dioxins above the uncontaminated reference controls. Low PAHs and PCBs were observed in the earthworms near or below the concentrations observed in the manufactured soil. The results of this phase of testing indicated that this type of manufactured soil that still contains contaminants should be used only on restricted locations such as landfills, acid minelands, and superfund sites that will have restricted human exposure and use. The final phase of testing for this beneficial use of the NY/NJ dredged material is a risk assessment of the human and ecological impacts of using this manufactured soil on landfills, acid mineland restoration, and superfund site remediation.
- **Construction blocks.** Another potential beneficial use selected for NY/NJ dredged material was construction blocks. A new innovative technology termed "Eco-Blocks"^R has emerged recently. The technology takes materials such as industrial waste (flyash, gypsum, sludge, cement), and/or consumer waste (windshield glass, construction rubble), and silt (dredged material) and combines them under a proprietary high-pressure and room-temperature technique to form a pozzolaic material shaped into blocks. These blocks have been tested at certified laboratories and have met ASTM standard and municipal building codes for

structural load and thermal resistance factors. The initial phase of characterization testing included grain size (No. 1, Table 1), water content (No. 3, Table 1) and Atterberg Limits (No. 5, Table 1). The dredged material was blended with other available materials in the NY/NJ Port area using proprietary techniques, and construction blocks were made. These blocks contained the contaminants present in the NY/NJ Harbor dredged material reduced in concentration due to blending with other materials and in an encapsulated form. The next phase of testing required for these blocks is actually manufactured product engineering tests for structural load and thermal resistance factors, environmental testing such as weathering and leachate testing, and risk assessment for the use of these blocks in various construction projects such as security walls, garden walls, planters, structural buildings, etc. The application of characterization tests to contaminated dredged material is more complex as in the case of the NY/NJ Harbor dredged material than that of less contaminated dredged material as in the previous cases of Mobile, AL, and Toledo, OH.

SUMMARY: The phased approach to characterization testing described in Technical Note DOER-C2 (Winfield and Lee 1999) should be employed in determining suitability for beneficial uses. Testing will be: Beneficial Use Suitability or Beneficial Use Selection. If a specific beneficial use can be selected initially, then those tests that provide the information required to make a decision on the acceptability of the processed dredged material for that beneficial use should be conducted (Beneficial Use Suitability Testing). If no specific beneficial use is selected initially, then more of the characterization tests listed in Tables 1 through 3 should be conducted to determine the suitability for a wider range of beneficial uses (Beneficial Use Selection Testing). Case studies of the use of appropriate characterization tests were discussed in this technical note to illustrate the decision process. It may not be necessary to conduct all of the characterization tests listed in Tables 1 through 3. Initially, characterization tests for determining the physical and engineering properties should be conducted, as required. If there is reason to believe the dredged material is contaminated, the chemical and/or biological characterization tests should be conducted. A modified version of the framework for testing and evaluating for beneficial use applications was described in Technical Note DOER-C2 (Winfield and Lee 1999) (Figure 1). If the results of the chemical/biological characterization tests indicate the potential for adverse impacts, the dredged material should be treated to manage the contaminants present in the dredged material, 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 use(s) can be realized. If adverse impacts are still indicated, the dredged material should not be used for beneficial purposes. The presence of contaminants in the dredged material results in a more complex decision process that should be conducted in a phased approach. Initial test results may lead to additional testing and risk assessment evaluation. Characterization testing can be applied to dredged material prior to placement in a CPF as described in the case of NY/NJ Harbor, where a CPF does not exist at present.

POINTS OF CONTACT: For additional information, contact the author, 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@wes.army.mil), and Dr. Robert M. Engler (601-634-3624, englerr@wes.army.mil). This technical note should be cited as follows:

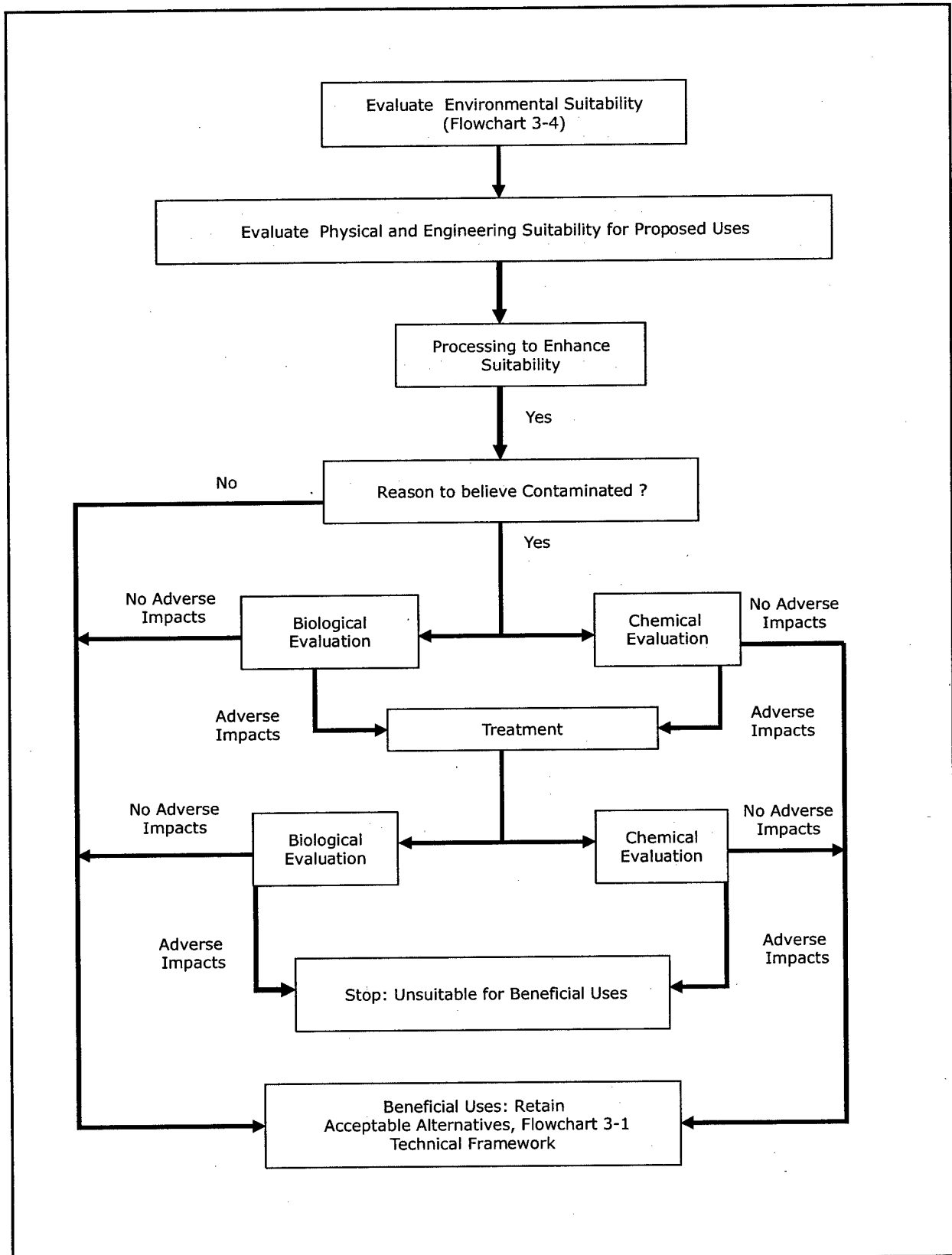


Figure 1. Framework for testing and evaluation for beneficial uses (figure revised July 1999)

Lee, C. R. (1999). "Case studies: Characterization tests to determine dredged material suitability for beneficial uses," *DOER Technical Notes Collection* (TN DOER-C7), U.S. Army Engineer Research and Development Center, Vicksburg, MS.
www.wes.army.mil/el/dots/doer

REFERENCES

- American Society of Agronomy. (1965). *Methods of soil analysis. Part 1. Physical and mineralogical properties, including statistics of measurement and sampling.* Madison, WI.
- American Society for Testing and Materials. (1996). *Annual book of ASTM standards.* Philadelphia, PA.
- American Society for Testing and Materials. (1998). "Standard guide for conducting laboratory soil toxicity or bioaccumulation tests with the lumbricid earthworm *Eisenia fetida*," *Annual book of ASTM standards.* Standard Guide E 1676-97, Philadelphia, PA.
- Bartos, M. J., Jr. (1977). "Classification and engineering properties of dredged material," Technical Report D-77-17, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Carter, M. R., ed. (1993). *Soil sampling and methods of analysis.* Canadian Soc. Soil Sci. Lewis Publishers. Boca Raton, Ann Arbor, London, Tokyo.
- Folsom, B. L., Jr., Lee, C. R., and Preston, K. M. (1981). "Plant bioassay of material from the Blue River dredging project," Miscellaneous Paper EL-81-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Greensberg, A. E., Clesceri, L. S., Eaton, A. D., and Franson, M. A. H. (1992). *Standard methods for the examination of water and wastewater.* 18th ed. American Public Health Assoc., American Water Works Assoc., and Water Environment Federation. Washington, DC.
- Headquarters, U.S. Army Corps of Engineers. (1986). "Laboratory soils testing," EM 1110-2-1906, Washington, DC.
- Lee, C.R., Folsom, B. L., Jr., and Bates, D. J. (1983). "Prediction of plant uptake of toxic metals using a modified DTPA soil extraction," *Sci. Total Environ.* 28, 191-202.
- Lee, C. R., Tatem, H. E., Brandon, D. L., Kay, S. H., Peddicord, R. K., Palermo, M. R., and Francingues, N. R., Jr. (1991). "General decision making framework for management of dredged material," Miscellaneous Paper D-91-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Lee, C. R., Sturgis, T. C., Cadet, W., Adams, P., and Drill, C. (1998). "Manufactured soil from dredged material, yardwaste, and EQ biosolids." *Proceedings of the Water Environment Federation 12th Annual Residuals and Biosolids Management Conference*, 12-15 July. Bellevue, WA, 674-704.
- Myers, T. E., and Brannon, J. M. (1988). "New Bedford Harbor Superfund Project, Acushnet River Estuary engineering feasibility study of dredging and dredged material disposal alternatives: Report 5, Evaluation of leachate quality," Technical Report EL-88-15, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Page, A. L., Miller, R. H., and Keeney, D. R., ed. (1982). *Methods of soil analysis. Part 2.* Am. Soc. Agronomy, Inc., and Soil Sci. Soc. Am., Inc. Madison, WI.
- Page, A. L., Miller, R. H., and Keeney, D. R., ed. (1996). *Methods of soil analysis. Part 3.* Am. Soc. Agronomy, Inc., and Soil Sci. Soc. Am., Inc. Madison, WI.
- Skogerboe, J. G., Lee, C. R., Price, R. A., Brandon, D., and Hollins, G. (1987). "Prediction of surface runoff water quality from Black Rock Harbor dredged material placed in an upland disposal site," Miscellaneous Paper D-87-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Spigolon, S. J. (1993). "Geotechnical site investigation strategy for dredging projects: Report 2, Geotechnical factors in the dredgeability of sediments," Contract Report DRP-93-3, prepared for U.S. Army Corp of Engineers, Washington, DC.
- Sturgis, T. C. and Lee, C. R. (1999). "Manufactured Soil Screening Test," *DOER Technical Notes Collection* (TN DOER-C6), U.S. Army Engineer Research and Development Center, Vicksburg, MS.

- U.S. Army Corps of Engineers and U.S. Environmental Protection Agency. (1991). "Evaluation of dredged material proposed for ocean disposal," Contract No. 68-C8-0105, Washington, DC.
- U.S. Army Corps of Engineers and U.S. Environmental Protection Agency. (1992). "Evaluating environmental effects of dredged material management alternatives - a technical framework," EPA 842-B-92-008, Washington, DC.
- U.S. Department of the Army, Navy, and Air Force. (1987). "Materials testing," Fiel Manual 5-530, U.S. Army Engineer School, Fort Belvoir, VA.
- U.S. Environmental Protection Agency. (1986). "Test methods for evaluation of solid waste," Office of Solid Waste and Emergency Response, Washington, DC.
- 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.