DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-76-4

FEASIBILITY OF THE FUNCTIONAL USE OF VEGETATION TO FILTER, DEWATER, AND REMOVE CONTAMINANTS FROM DREDGED MATERIAL

by

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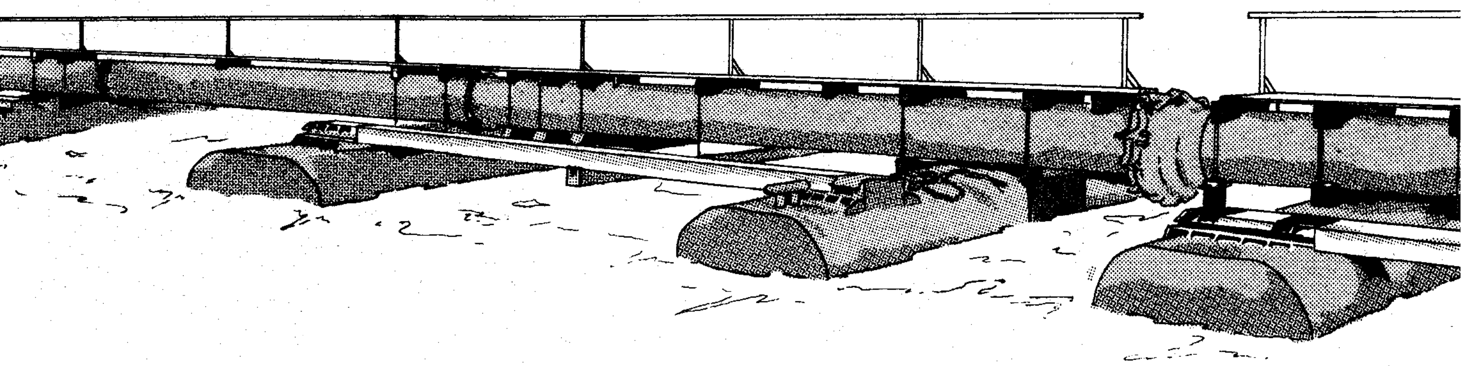

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1. The report transmitted herewith represents the results of one of the work units of Task 2C (Containment Area Operation Research) of the Corps of Engineers' Dredged Material Research Program (DMRP), administered by the Environmental Effects Laboratory (EEL), Waterways Experiment Station (WES). Task 2C is included as part of the DMRP Disposal Operations Project, which, among other considerations, includes research into various ways of improving the acceptability of facilities for confining dredged material on land.

2. Until recently, practically no specific design, construction, or operational improvement investigations or research had been conducted with regard to the confinement of dredged material on land. There has been a dramatic increase in the last several years in the amount of land disposal necessitated by confining dredged material classified as polluted. Attention necessarily is directed more and more toward the environmental consequences of this disposal alternative.

3. DMRP work units are in progress investigating improved facility design and construction and concepts for increasing facility capacities for both economic and environmental purposes. However, the total picture would be incomplete without considering improved facility operation and management through the use of low-cost material or resources naturally occurring at the site. To this end, the study reported herein was accomplished by EEL's Ecosystem Research and Simulation Division. The study investigated the capability of vegetation to filter, dewater, and/or remove contaminants from dredged material and the effluent from confined containment areas. Consideration was given to vegetation that naturally invades a disposal site as well as those species that could be deliberately established to achieve a desired result. The investigation was basically a state-of-the-art study based on a literature review and information obtained from numerous consultants.

4. Available information was compiled and an assessment was made of the feasibility of using vegetation to filter, dewater, and remove contaminants

from dredged material slurry and effluent from confined disposal areas. A summary was developed that provides a listing of plant species that might be propagated on disposal areas. The following conclusions were drawn from the information assessment:

a. The physical and chemical interactions of selected vegetation with dredged material will improve the quality of the discharge water from containment areas; also vegetation outside the containment area may be used to improve the quality of the effluent before it returns to the receiving waters.

b. Significant amounts of nitrogen and phosphorus could be removed from the discharge water by use of selected vegetation. The use of vegetation to remove large amounts of heavy metal contaminants from dredged material has limited feasibility.

c. The intolerance of some plants to certain contaminants may preclude their usefulness in dredged material disposal areas.

d. The use of selected vegetation to dewater and consolidate fine-textured dredged material is feasible.

e. Vegetation can be used to improve the appearance of a confined disposal area.

f. The practicability of establishing and using vegetation will depend on the planned future utilization of the disposal area or the dredged material contained therein.

5. Field tests have already been initiated within Task 2C to evaluate the effectiveness of vegetation for dewatering dredged material. Field tests are being planned as part of Task 6B (Treatment of Contaminated Dredged Material) to investigate the use of vegetation for removing contaminants from dredged material effluent. Other field tests are being conducted as part of Task 5A (Dredged Material Densification) to evaluate the performance of vegetation for dewatering the upper portion of the containment area to produce a stable surface on which to operate construction equipment.

JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

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Available information was compiled and an assessment was made of the feasibility of using vegetation to filter, dewater, and remove contaminants from dredged material slurry in confined disposal sites. From the information obtained, a summary was developed to provide a listing of plant species that might be propagated on disposal areas. It was concluded that the physical and chemical interactions of selected vegetation with dredged

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material slurry will improve the quality of the discharge water from containment areas. Significant amounts of nitrogen and phosphorus could be removed from discharged waters by the use of selected vegetation. The use of vegetation to remove large amounts of heavy metal contaminants from dredged material has limited feasibility. The intolerance of some plants to certain contaminants may preclude their usefulness in dredged material dispòsal operations. The use of selected vegetation to dewater and consolidate fine-textured dredged material is feasible. The presence of vegetation will improve the appearance of confined disposal areas. The practicality of establishing and using vegetation will depend on the planned future use of disposal areas or the dredged material contained therein.

PREFACE

This investigation, based primarily on a literature review, examined the feasibility of using vegetation to filter, dewater, and remove contaminants from dredged material placed in a containment area. The investigation was conducted as part of the Corps of Engineers Dredged Material Research Program (DMRP). The DMRP is sponsored by the Office, Chief of Engineers (DAEN-CWO-M) and is administered by the Environmental Effects Laboratory (EEL), U. S. Army Engineer Waterways Experiment Station (WES).

This study was conducted during the period of November 1973 through December 1974 by Drs. C. R. Lee and P. G. Hunt and Messrs. R. E. Hoeppel and C. A. Carlson under the general supervision of Dr. R. L. Eley, Chief, Ecosystem Research and Simulation Division, and Dr. John Harrison, Chief, EEL. Dr. J. W. Barko, EEL, provided assistance in the review and modification of the manuscript. The study was undertaken as part of Task 2C, Containment Area Operations Research of the DMRP Disposal Operations Project (DOP). The DOP manager was Mr. C. C. Calhoun, Jr., and the Task 2C manager was Mr. N. C. Baker.

Technical consultants during the study were Dr. W. H. Patrick, Professor of Agronomy, Louisiana State University (LSU), and Dr. R. H. Chabreck, Associate Professor of Forestry and Wildlife Management, LSU. Cooperation and assistance were received from the following Corps of Engineers District personnel: Messrs. V. Bordelon, Chief, and C. Elfanso, Operations Division, New Orleans District; Mr. John Carothers, Chief, Recreation Environmental Resources Section, Charleston District; Mr. H. Griffiths, Disposal Site Section, Philadelphia District; Messrs. B. Bochantin, J. J. Parez, and J. C. I. Choe, Operations Division, Chicago District; Mr. G. N. Bigham, Environmental Resources Division, Los Angeles District; and Messrs. A. Heineman, Chief, C. Galloway, G. Harteman, V. Schweitz, and J. Patching, Navigation Division, Portland District.

Additional assistance was obtained from a number of scientists including Dr. C. E. Boyd, Assistant Professor of Fisheries and Allied

Aquacultures, Auburn University; Dr. E. P. Dunnigan, Associate Professor of Agronomy, LSU; Dr. J. G. Gosselink, Coastal Studies Institute, LSU; Dr. W. W. Woodhouse, Jr., Professor of Soil Science, North Carolina State University; Dr. E. Garbisch, Environmental Concern, Inc., St. Michaels, Maryland; and Mr. L. Banks, Biological Water Purification, Inc., New York, New York.

The Director of WES during the study and preparation of this report was COL G. H. Hilt, CE. Technical Director was Mr. F. R. Brown.

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PART I: INTRODUCTION

Background

1. Navigable waterways of the United States have, through the years, played a vital role in the Nation's economic growth. The Corps of Engineers (CE), in fulfilling its mission to develop and maintain these waterways, is responsible for the dredging of large volumes of sediment each year. With increased concern over environmental degradation, the disposal of dredged sediment has received increasing attention in recent years. The Dredged Material Research Program (DMRP) was authorized to provide definitive information on the environmental impact of dredging and dredged material disposal operations. The DMRP was undertaken to develop alternative dredging and disposal methods that are technically satisfactory, environmentally compatible, and economically feasible.

2. A report,[1] submitted to the President by the Council of Environmental Quality in October 1970, recommended that ocean dumping of contaminated dredged material be phased out as soon as alternatives could be employed and that the dumping of uncontaminated dredged material be regulated to prevent damage to estuarine and coastal areas. Confined land disposal was discussed as an interim alternative for the disposal of contaminated dredged material with a warning that this alternative is not without environmental problems. More stringent regulatory criteria may result in more and more sediments being classified as too contaminated for discharge into open water. Therefore, it is necessary that the development of alternative disposal methods be expedited.

3. Confined disposal of dredged material has been hampered for a number of years by certain associated problems.[2] Fine-textured

sediments become suspended during dredging and disposal operations and frequently are reintroduced into the waterway. In an effort to determine the feasibility of developing methods to lessen environmental perturbation by poor-quality discharge waters from diked confinement areas, this study was undertaken.

4. The dewatering of fine-textured sediments subsequent to confined disposal is another problem. The drying process is important because it promotes consolidation, thereby increasing the capacity of the disposal site. Crust formation at the surface of the slurry (Figure 1) may hinder the drying of the material below the crust. Consequently, some sites remain unconsolidated for extended periods of time and lack the stability to support men or machinery.

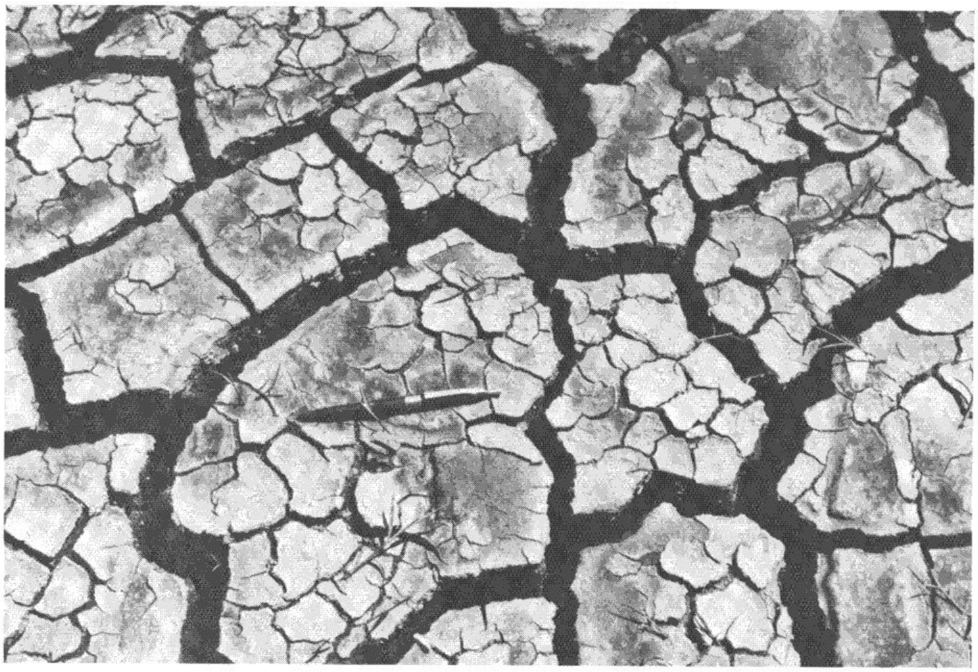

Figure 1. Crust and crack formation at the surface of confined dredged material

Purpose

5. The purpose of this study was to compile available information on and to assess the feasibility of using vegetation to filter, dewater,

and/or remove contaminants from dredged material slurry in confined disposal sites. This report will serve as an introduction to and partial data base for subsequent research for this alternative of dredged material disposal.

Scope

6. Dredged material and potential vegetative colonizers from freshwater, brackish, and saline environments were considered in six geographic regions of the United States: Northwest, Southwest, Gulf, Great Lakes, Northeast, and Southeast. While this report discusses a large number of plant species, there are undoubtedly other plant species that might have potential for use in confined disposal sites.

PART II: APPROACH

7. The study was conducted in two phases: (a) a literature review phase and (b) a field observation phase. Selected consultants reviewed and modified a preliminary list of various plant species with suspected capability for growth in confined disposal areas. A literature review was conducted to obtain more specific information regarding the ability of these plant species to filter, remove contaminants from, and dewater dredged material.

8. Field trips were made to confined disposal sites,* some of which had been previously visited by other DMRP contractors, in order to generate complementary information. In collaboration with CE District personnel, disposal operations were observed and potential problems noted. Natural vegetation inside each disposal site and within the immediate vicinity was identified.

9. A list of the vegetation discussed in this report is contained in Appendix A. From the information obtained, a summary was compiled to provide a listing of plant species that might be propagated on disposal areas. This list, given in Appendix B, presents details of the major findings of the study. Each species is described in terms of habitat and growth characteristics and is evaluated for potential use in disposal areas.

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* Confined disposal sites were visited in the Portland, Los Angeles, New Orleans, Charleston, Philadelphia, and Chicago Districts.

PART III: RESULTS

Potential Applications

10. The quality of discharge waters from containment areas is affected by contaminants and turbidity that may be associated with the dredged sediment. It is proposed that such conditions may be ameliorated by using vegetation to filter the incoming dredged material slurry, thereby reducing turbidity and removing contaminants.

11. As confined land disposal of dredged material increases, the availability of land for disposal will decrease. Dewatering of the dredged material will increase the capacity of the disposal area and improve the engineering properties of the contained material. Vegetative transpiration is proposed as a means of dewatering dredged material.

Use of Vegetation for Slurry Filtering

12. The ability to reduce levels of turbidity, remove surface foams, and trap floating debris from dredged material slurries discharged into diked containment areas is very much dependent upon the ability of the containment area to disperse the energy associated with influent discharge. For this purpose, techniques such as interior dikes are commonly used to maximize the residence time within the containment area. However, bed erosion, short circuiting, wind, and turbulent flow near the sluice create problems in even well-constructed land disposal areas.

13. The use of vegetation inside disposal sites to filter dredged material slurry appears to have good potential. In observations at several confined disposal sites, the discharge waters appeared cleaner where vegetation was present prior to dredging and disposal operations than at sites where vegetation was absent. Various CE District personnel have noted that vegetation commonly improves the clarity of discharge waters leaving confined disposal sites.

14. The use of vegetation is recommended for the dewatering of fine-textured dredged material. Coarse-textured material (e.g. sandy sediments) settles out within a short distance from the discharge pipe. In this case, stabilization of substrata probably would not be enhanced by the presence of vegetation.

15. Physical and chemical interactions between vegetation and dredged material slurry are very complex and are not always predictable or definable. However, some generalizations can be made that describe interactions between major constituents of dredged sediments and vegetation.

16. The lignin-humus complex represents the major organic fraction of soils and bottom sediments.[3-5] Under conditions of normal pH, the primary components of this complex are typically negatively charged and tend to disperse similarly charged clays. However, at the same time, these components can adsorb and complex positively charged cations such as heavy metal contaminants.[6] Mobile organic compounds are able to carry adsorbed contaminants from the disposal site.[7,8] In this way the lignin-humus complex may contribute to the concentration of contaminants in discharged waters.

17. Although the growth and decomposition of higher plants produce some macromolecules similar to the lignin-humus complex, the most important organic compounds released by plants are various proteins, polysaccharides, and their constituents. While the globular humus molecules in bottom sediments tend to disperse clays, most macromolecules produced by plants acquire a planar orientation and thus aid in the flocculation and agglomeration of clays and other hydrophobic particles.[5,6,9] The effect is similar whether the compounds are electrically charged (polar) or electrically neutral (nonpolar). In contrast to the refractory organic molecules in bottom sediments, those produced by vegetation may be important in reducing turbidity (c.f. References 5,6,9). However, the general importance of this chemical phenomenon is difficult to assess from the available information.

18. Based on the findings of this investigation, it is recommended that vegetation be used to decontaminate and reduce the

turbidity of discharge waters from disposal sites where the use of vegetation is not restricted by other considerations. Various physical and chemical plant-substratum interactions appear to be important in the process of slurry filtering. The interactions are discussed theoretically in Appendix C. Details of the process of slurry filtering and delineation of the more important mechanisms involved have not been resolved empirically, however. It is suggested that field studies conducted concurrently with large-scale greenhouse efforts be implemented to provide such information.

Contaminant Removal by Vegetation

19. Sediments accumulated in waterways may contain variable kinds and quantities of contaminants that may become concentrated in dredged material containment areas. Information gathered in this study indicates that certain types of vegetation may be effectively used to clean discharge waters from confined disposal sites, thus minimizing contamination of the adjacent aquatic environment.

20. Vegetation has been demonstrated to be effective in the removal of nitrogen and phosphorus from waste lagoons.[10] It is expected that vegetation would also be effective in the removal of these and other nutrients from dredged material slurries, thereby reducing the biological impact of effluent from containment areas on adjacent waterways.

21. Other elemental contaminants, found in dredged material and of biological concern from the standpoint of their potential toxicity, can be divided into three general groups based on their concentration in plant tissue as well as their effect on plant growth and development.

- a. Those elements that are not taken up in large quantities by most plant species.
- b. Those elements that are often taken up in relatively large quantities by certain plant species.
- c. Those elements that can be toxic to some plant species when taken up in either greater or lesser amounts.

22. Most plants do not concentrate large quantities of lead or

cadmium, yet it has been demonstrated that some forage plants can accumulate quantities of these that are toxic to grazing animals, without appreciably affecting the growth of the plants themselves.[11] One of the more common plant species, Myriophyllum spicatum, has been reported to take up large quantities of mercury,[12] another toxin capable of detrimentally affecting consumer organisms. Zinc, copper, and nickel are other elements that can be selectively concentrated to a lesser extent within the tissue of some plants.

23. Oil, grease, and some other organic compounds are slowly degraded and thus more difficult to remove, particularly if they are chemically suspended. It is therefore important to note that vegetation used in dredged disposal operations may have to tolerate significant quantities of oil and grease. These compounds, as well as the elements sulfur, aluminum, iron, and manganese, can be toxic to some types of vegetation. A more detailed discussion of these and other contaminants of dredged material is given in Appendix D. The relative capacity of a number of selected plant species to tolerate or remove various chemical contaminants is summarized in Appendix B.

24. One method that might further minimize the contamination of waterways in the discharge area would be the establishment of a vegetated overland flow system through which discharge waters would pass between the outlet weir and the adjacent waterway (Figure 2).

25. Vegetation used either inside the disposal site or in an overland flow treatment area could be harvested periodically to facilitate nutrient and contaminant removal. Harvesting should not be undertaken before the vegetative community has become stabilized. The vegetation should be harvested judiciously on a seasonal basis to ensure maximum efficiency in the removal process. It would be desirable to provide an economic impetus to the harvesting process because of the expense involved. Although harvested aquatic vegetation has been used as a food supplement for cattle, chickens, and swine, alternative uses such as paper manufacture, if economically feasible, would be much better.[13]

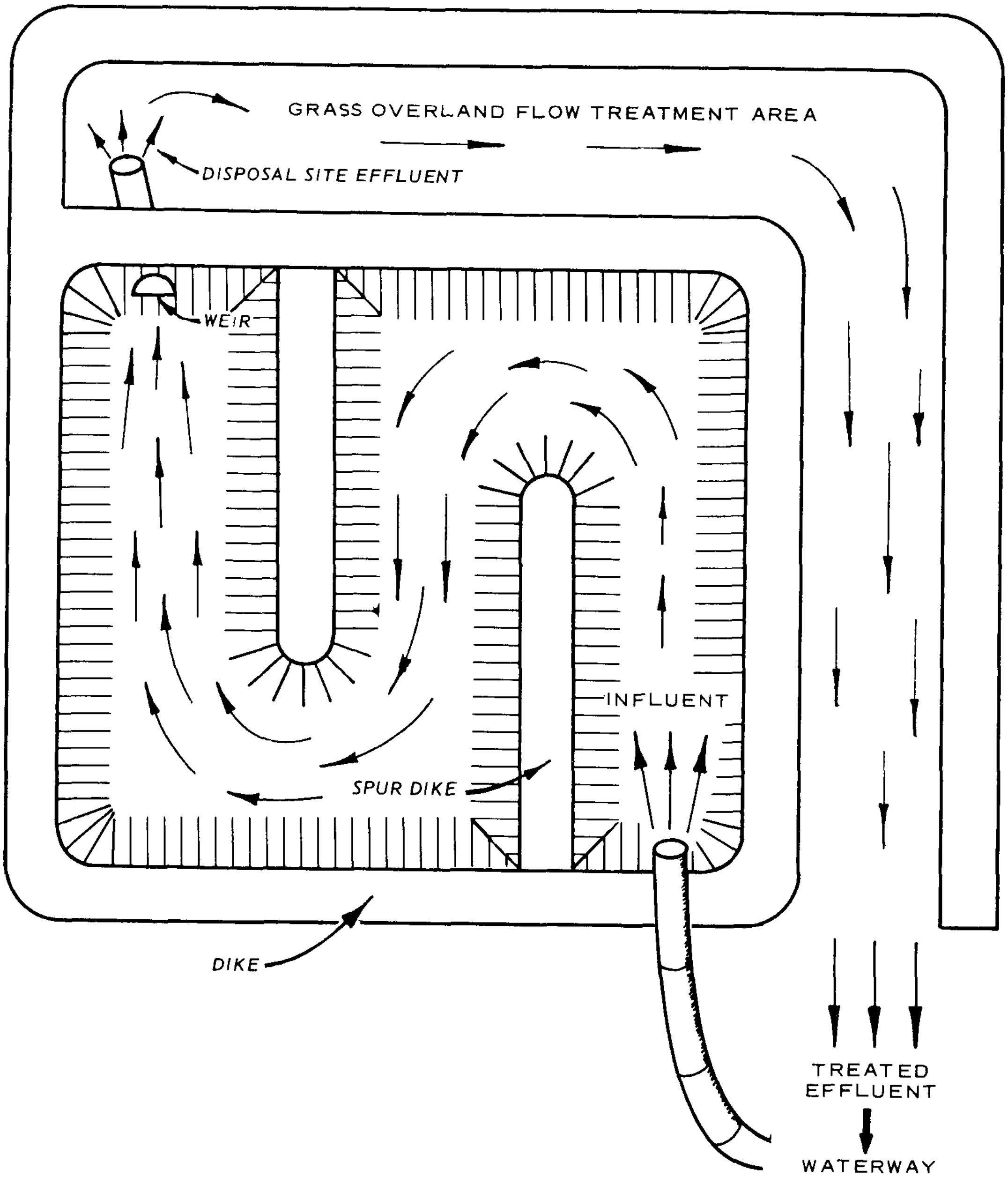

Figure 2. Incorporation of overland flow as a final treatment of discharge waters

Dewatering of Dredged Material

26. In order for consolidation of dredged material to occur, substantial drying must take place. Furthermore, this drying must proceed to a considerable depth rather than be limited to the surface if

significant increases in the capacity of the area are to be realized.

27. Conventional techniques for dewatering and stabilizing soils are generally not economically feasible because of the vast areas and quantities of dredged material involved in land disposal operations. Soil reclamation by vegetative dewatering is not as expensive as most conventional techniques, and it has been accomplished for many years by the Dutch, who have successfully dewatered both lacustrine and marine sediments.[14,15]

28. An important question in assessing the applicability of vegetative dewatering is that of the extent to which vegetation can dry a soil. Dredged material, after settling in a diked disposal area, has a higher water content than that of normally saturated terrestrial soils; the water content in both cases obviously exceeds the liquid limit.[16] After vegetative drying to 15-atm tension, the water contents of soils normally range from 5 percent for sands to 20 percent for clays, values that are less than the plastic limits of most soils. Based on the relationship between liquid limit and shrinkage limit, it appears that most dredged material would have reached its shrinkage limit after vegetative drying to 15 atm.

29. Vegetative dewatering of soil results from the movement of water into the plant root, up the stem, and out the leaves, a process referred to as transpiration. Drying is primarily limited to the depth of root penetration and is proportional to the extent of foliar surface. Some plants are capable of extending their roots several metres into the soil to the water table. These plants are able to transpire larger amounts of water than those demonstrating lesser root development. Other plants, well suited for the dewatering of dredged material, are able to extend themselves vegetatively even when covered with as much as 2 m of soil. Appendix E contains a more detailed discussion of plant characteristics desirable for dewatering purposes. Appendix B relates desired features with intrinsic characteristics of several plant species.

30. Surface evaporation would appear to have a much lesser effect on soil moisture tension than does vegetative dewatering. As

soil dries, capillary conductivity across the drying layers approaches zero, and liquid flow to the surface soon ceases.[17] In view of this phenomenon, it is easy to understand why most dredged material in diked areas rapidly form a thin crust (10 to 30 cm) of dry material, beneath which exists material with a high moisture content that may not dry for many years, if ever. A more detailed discussion of why vegetative dewatering is considerably more extensive than physical dewatering due to surface evaporation is given in Appendix E.

31. Although there have been no studies on the vegetative dewatering of dredged material, there does appear to be sufficient information available to support the feasible use of vegetation in this capacity. Questions regarding selection of species, methods of planting, critical density, plant community regulation, and harvesting techniques are but a few of those that must be resolved before this method proposed for dewatering dredged material can be implemented.

Reuse of Dredged Material Disposal Sites

32. The ease and quickness with which a disposal site can be used after it is filled to capacity vary from site to site. Several disposal areas visited during this study had been designated as future industrial development sites. The establishment of plant species able to increase the rate of dewatering would significantly shorten the time span between dredged material disposal and industrial development of these areas, and also would provide cover for wildlife habitat, and control of dust and erosion in the interior.

33. The presence of vegetation would be most important on disposal sites designated for long-term use, particularly those containing fine-grained sediments. In this situation vegetation should be selected that would most effectively filter the dredged material slurry, remove certain contaminants from effluent waters, and dewater the remaining dredged material.

34. The use of vegetation is not recommended for all disposal areas. In general, the establishment of vegetation should be

discouraged in disposal areas where the dredged material is specified for use in road construction or for agricultural purposes. Mr. H. Griffiths, of the Philadelphia District, related an example of the continued regrowth of *Phragmites communis* (common reed grass) on dredged material, which although potentially well suited for crop production, lost its agricultural value because of this uncontrollable regrowth (personal communication).

35. Coarse-grained dredged material (e.g. sand) is typically free draining and therefore the stabilization of such material would not likely be enhanced by the establishment of vegetation. The suitability of sandy dredged material for construction purposes also is partially dependent upon the absence of organic matter.

Cost of Establishing Vegetation

36. Some of the more important factors affecting the total cost of artificially vegetating a dredged material containment are: (a) source of plant material, (b) method of transplanting, and (c) desired density of plant propagules. Dependent upon these and other considerations, the cost would likely vary considerably between different disposal areas. Although detailed cost analyses have not been resolved, the expense involved in establishing vegetation at a particular disposal site can be inferred from information obtained through personal communication with individuals who have previously attempted to establish vegetation under similar conditions.

Source of plant material

37. Two sources of plant material are available: natural and commercial. Natural vegetation, when removed from an adjacent marsh area and transplanted within a diked confinement, has the advantage of being already climatized. Local authorities should be consulted, however, regarding the legality of plant removal from natural areas. Most of the expense incurred in this type of planting operation would be for labor.

38. The cost involved in purchasing plants from a commercial

enterprise varies depending on the availability of the propagules required. While some species can be propagated and grown from seed, vegetative propagation is generally more successful. Mature plants generally cost more than seedlings due to the nursery expenses involved. Because of the supplemental lighting and heating required, the acquisition of commercially available vegetation during winter months can be expected to be more expensive than during summer months.

Method of transplanting

39. Techniques for the establishment of marsh plant communities are primitive. A mechanical dune-grass transplanter, although successfully used to plant Spartina alterniflora,[18] is limited to operation on firm dredged material and to the planting of small plants. Until better techniques are developed, it appears that hand planting is more practical in most locations.

40. It is recommended that containment areas be planted prior to introduction of dredged material and that sufficient time (several months to one year) be allowed for the establishment of the plant community. The absence of vegetation in a containment area at the time of disposal precludes vegetative slurry filtering. Because of the intolerance of many plant species to burial beneath dredged material, it may be necessary to propagate containment areas following termination of disposal operations. Extreme caution is required when working on fresh dredged material that lacks sufficient density to support the weight of a human.

Plant population density

41. Although the cost of planting increases proportionately with the number of propagules used, provision should be made for the establishment of a plant community having a density that will effectively filter and dewater dredged material. Population densities of approximately 12,400 plants per hectare have been reported for Spartina alterniflora and other marsh grasses in marsh creation projects.[18] Phragmites communis has been planted at a density equivalent to 49,400 plants per hectare in diked confinements in the Detroit, Michigan, area into which dredged material was deposited in connection with a field

demonstration. The spread of most perennial marsh plants is very rapid when conditions for growth are optimal. Given adequate time to autonomously colonize containment areas, the number of propagules introduced could be kept at a minimum. Further research is necessary to determine the minimum number of plants required to effectively colonize containment areas for purposes of slurry filtering and dewatering.

Cost estimate*

42. The cost of establishment of two-month-old plant species at a density of 12,400 plants per hectare is estimated at approximately $4,900 to $6,200 per hectare for naturally available vegetation and $6,900 to $8,200 per hectare for commercially available vegetation. Plant species commercially available include *S. alterniflora*, *S. patens*, *S. cynosuroides*, *Scirpus robustus*, *Distichlis spicata*, and *Typha latifolia*.

43. These estimates of cost, based on area planted, are misleading since they are not adjusted for the volume of dredged material potentially contained at a disposal site. As containment areas are reused following the initial establishment of a vegetative community, the cost per volume of dredged material decreases linearly.

Aesthetic Considerations

44. Historically, confined dredged disposal sites have been public eyesores because they frequently remain barren wastelands for years (Figure 3). The presence of vegetation on confined disposal areas would greatly improve their general appearance. Plant species listed in Appendix B (Table B1) were evaluated for aesthetic qualities. Most of these plants have attractive leaves; the water hyacinth (*Eichornia crassipes*) and the water primroses (*Jussiaea* spp.) exhibit especially showy flowers and have pleasant fragrancies.

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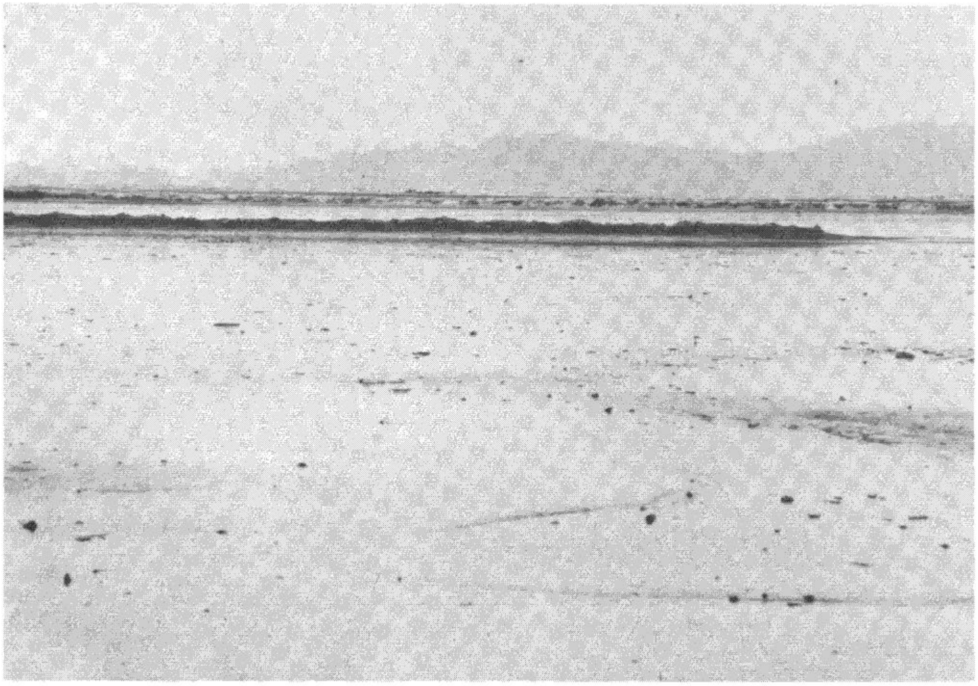
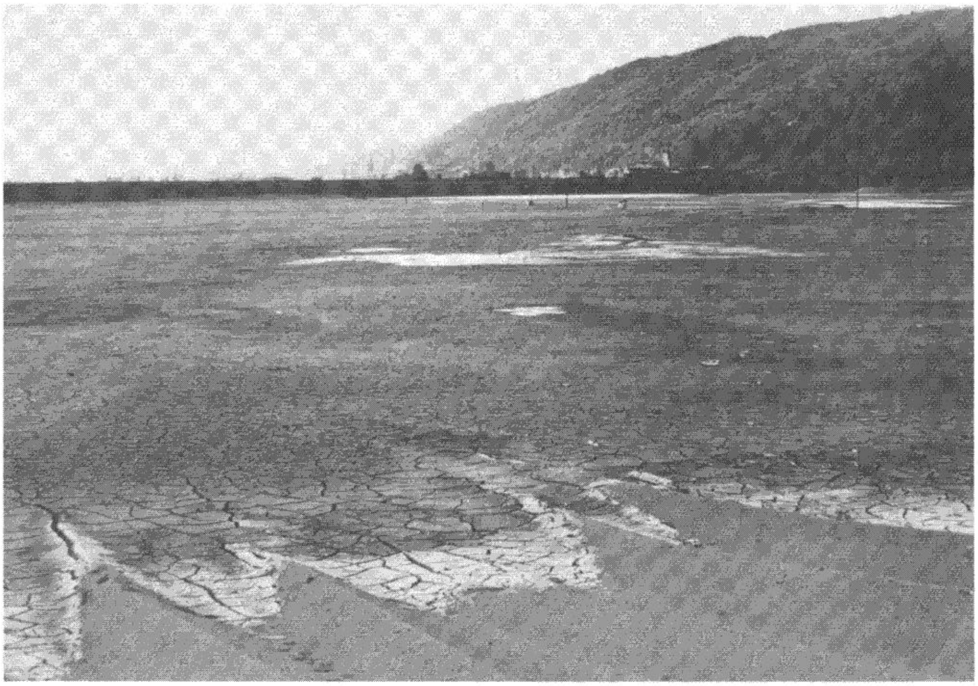
* Based on 1974 prices and personal communications with Dr. W. W. Woodhouse, North Carolina State University, Raleigh, N. C.; Dr. E. Garbisch, Environmental Concern, Inc., St. Michaels, Md; and Mr. L. Banks, Biological Water Purification, Inc., New York, N. Y.



a. Coos Bay



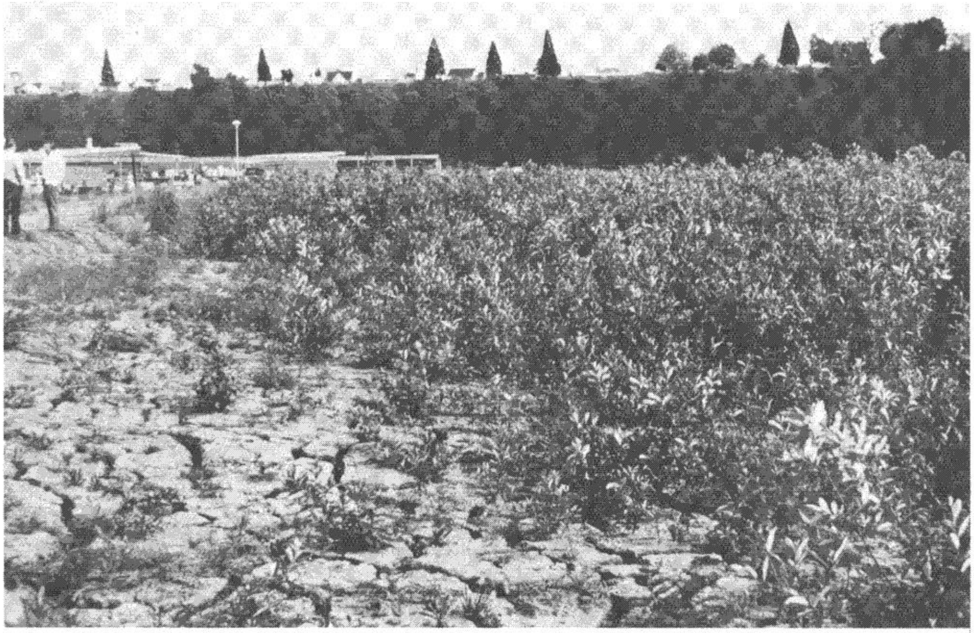
b. Portland

Figure 3. Barren appearance of two disposal sites at Coos Bay and Portland, Oregon

45. A number of disposal sites observed in this investigation were densely covered with naturally colonizing willow (*Salix* spp.) and cottonwood (*Populus* spp.) (Figure 4). In Philadelphia, thick stands of common reed (*Phragmites communis*) made it virtually impossible to distinguish disposal areas from the natural surroundings.

Control of Vegetation

46. Because of their potential for rapid growth and dispersal, a number of the plant species listed in Appendix B (Table B1) are considered weeds. In regions where they are not native, definite measures should be taken to restrict such plants to disposal areas. Management of weeds is routinely accomplished by chemical, biological, and mechanical means, or by combinations thereof.[19] Chemicals commonly used in the control of weedy plant species are listed in Appendix B (Table B1). It is recommended that, whenever possible, only native vegetation be used in the establishment of plant communities at dredged material disposal sites. Aside from being biologically sound reasoning, the implementation of this policy will preclude unnecessary expenditure for weed control and should avoid litigations on environmental grounds.



a. Salix spp., Portland, Oregon

b. Salix spp. and Populus spp., Chicago, Illinois

Figure 4. Disposal sites naturally vegetated with Salix spp. at Portland, Oregon, and Salix spp. and Populus spp. at Chicago, Illinois

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

47. Based on results of this study, the following conclusions are outlined:

- a. The physical and chemical interactions of selected vegetation with dredged material slurry will improve the quality of the discharge water from containment areas.
- b. The use of selected vegetation to remove significant amounts of nitrogen and phosphorus from discharge waters is feasible.
- c. The use of selected vegetation to remove heavy metal contaminants from dredged material has limited feasibility. The intolerance of some plants to certain contaminants may preclude their usefulness in dredged material disposal operations.
- d. The use of vegetation should be restricted when the dredged sediments contain high levels of mercury, lead, or cadmium, elements that readily become toxic when concentrated in the food chain.
- e. Dredged material contamination by mercury, lead, or cadmium negates the use of some disposal areas as wildlife habitat.
- f. In containment areas where oil and grease films are troublesome contaminants, vegetation can serve to collect and thus confine these materials. Thick accumulations of oil and grease in dredged sediments may, however, detrimentally affect plant growth in these containment areas.
- g. The use of vegetation to dewater and consolidate fine-textured dredged material is feasible. Although coarse-textured sediments need not be vegetatively dewatered to achieve consolidation, vegetation would serve in nutrient and contaminant removal and increase the aesthetic value of the area containing this type of dredged material.
- h. Vegetation will improve the appearance of confined disposal areas.
- i. Whenever possible, native plant species rather than introduced species should be used to colonize dredged material disposal areas.
- j. Plans for the future use of disposal areas or the dredged material contained therein should dictate the practicality of establishing vegetation.

Recommendations

48. It is recommended that natural vegetation occurring within a disposal site be left intact and advantage taken of the existing vegetation to filter dredged material slurry.

49. It is recommended that further research be conducted to better elucidate design criteria for the efficient use of vegetation in confined disposal areas. Greenhouse and field studies should be conducted to (a) evaluate the ability of selected plant species to filter dredged material slurry and remove soluble nutrients from discharge waters and (b) determine the dewatering capabilities of selected plant species.

50. The uptake of toxic substances from some dredged material by plants and the potential for concentration of these contaminants in various segments of both grazing-based and detrital-based food chains should be evaluated closely before land disposal of dredged material becomes routine.

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APPENDIX A: LIST OF VEGETATION DISCUSSED IN THIS REPORT

Scientific Name	Common Name	Reference*
Acacia spp.	acacia	20
Allenrolfea occidentalis	pickleweed	—
Alnus spp.	alder	20
Alternanthera philoxeroides	alligator weed	21, 22, 23, 24, 25, 26, 27, 28, 29, 30
Ammophila breviligulata	American beachgrass	31, 32
Arundinaria gigantea	giant cane, bamboo	32
Arundinaria tecta	switch cane, bamboo	32
Arundo donax	giant reed	32
Baccharis halimifolia	groundsel bush, buckrush	33, 34, 35, 36, 37
Carex spp.	sedge, carex	25, 26, 36, 38
Chrysothamnus spp.	rabbit brush	25
Colza spp.	rape seed	14
Cynodon dactylon	bermuda grass	36, 39
Cyperus esculentus	nutsedge	25, 40
Distichlis spicata	salt grass	26, 37, 41
Echinochloa crus-galli	barnyard grass, millet	32, 42
Eichornia crassipes	water hyacinth	21, 23, 25, 27, 28, 43, 44, 45, 46, 47
Eucalyptus spp.	eucalyptus, blue gum	20
Eucalyptus botryoides	bangalay	—
Eucalyptus globulus	blue gum	—
Eucalyptus miltriflora	eucalyptus	—
Eucalyptus umbellata	horncap	—
Fraxinus spp.	ash	14, 20
Glyceria spp.	mannagrass	32
Iris spp.	iris	—
Iva frutescens	marsh elder, gall bush	22, 24, 35, 48
Juncus effusus	common rush, bog rush	21, 35, 36, 38, 49, 50, 51, 52, 53
Juncus gerardii	a European species	54
Juncus roemerianus	black rush, needlerush	22, 23, 31, 35, 41, 43, 51
Juncus maritimus	a European species	55
Jussiaea spp.	water primrose	21, 25
Justicia americana	water willow	27, 28, 29, 30
Lemna spp.	common duckweed	10, 56, 57, 58, 59

(Continued)

* Reference numbers refer to similarly numbered items in the list of references following the main text.

Scientific Name	Common Name	Reference
Medicago sativa	alfalfa	14, 38, 39, 60
Myriophyllum spp.	watermilfoil	21, 25, 61
Myriophyllum spicatum	Eurasian watermilfoil	13, 27, 61
Panicum hemitomon	maidencane	26, 32
Panicum virgatum	switchgrass	26, 31, 32, 51, 62
Phalaris arundinacea	reed canarygrass	32
Phragmites communis	common reed, roseau cane	14, 20, 21, 23, 24, 26, 31, 32, 37, 38, 41, 43, 49, 51, 59, 63, 64, 65, 66
Phyllostachys spp	dwarf bamboo	32
Pistia stratioites	water lettuce	21, 45
Platanus spp.	sycamore	67
Populus spp.	cottonwoods	14, 36, 67
Populus deltoides	cottonwood	42, 68
Populus heterophylla	swamp cottonwood	69
Populus tacamahaca	tacamahaca	69
Populus trichocarpa	black cottonwood	69
Potamogeton spp.	pondweed	—
Potamogeton diversifolius	pondweed, Rafinesque's pondweed	23, 25, 49, 50, 52, 70, 71
Potamogeton foliosus	leafy pondweed	23, 25, 50, 52, 70, 71
Potamogeton illinoenis	Illinois pondweed	21, 23, 25, 49, 50, 52, 70, 71
Potamogeton nodosus	common American pondweed	23, 25, 49, 50, 52, 70, 71
Potamogeton pectinatus	sago pondweed	23, 25, 49, 50, 52, 70, 71
Potamogeton pusillus	slender pondweed	23, 25, 50, 52, 70, 71
Potamogeton richardsonii	Richardson pondweed	23, 25, 49, 50, 52, 70, 71
Prosopis juliflora	mesquite	36, 38
Pseudosasa japonica	dwarf bamboo	32
Puccinellia maritima	alkali grass	32, 54, 55
Sagittaria falcata	bulltongue	26, 41
Sagittaria latifolia	arrowhead, duck potato	71
Salicornia spp.	glasswort	72
Salix spp.	willow	14, 42, 69, 73
Salix nigra	black willow	26, 42
Sambucus	elderberry	—
Sarcobatus spp.	greasewood	36, 38
Scirpus americanus	freshwater threesquare	22, 23, 26, 31, 44, 49, 50, 74

(Continued)

Scientific Name	Common Name	Reference
Scirpus acutus	hardstem bulrush	23, 33
Scirpus californicus	hardstem bulrush, bullwhip	26, 75, 76
Scirpus olneyi	olney threesquare three-cornered grass	23, 26, 31, 44, 77
Scirpus robustus	salt marsh bulrush	23, 26, 31, 77
Scirpus validus	softstem bulrush	21, 22, 23, 26
Setaria italica	foxtail millet	32
Spartina alterniflora	salt marsh cord grass, smooth cord grass	18, 22, 23, 31, 32, 35, 41, 52, 54, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88
Spartina anglica	British spartina	55
Spartina cynosuroides	big cord grass	23, 31, 32, 41
Spartina foliosus	California spartina	32
Spartina patens	salt meadow hay, salt meadow cord grass	23, 26, 31, 32, 35, 41, 43, 48, 51, 77, 86, 89
Spartina pectinata	prairie cord grass	23, 32
Spartina townsendii	European spartina	54
Spirodela spp.	giant duckweed	10, 56, 58, 59
Tamarix gallica	saltcedar, tamarisk	22, 23, 36, 39
Trifolium spp.	clover	14
Triticum spp.	winter wheat	14
Typha spp.	cattail	21, 22, 23, 25, 30, 38, 51, 59, 71, 90
Typha angustifolia	narrow-leaved cattail	26, 31
Typha latifolia	broad-leaved cattail	31
Zizaniopsis miliacea	giant cutgrass, water millet	21, 22, 24, 26, 27, 32

APPENDIX B: SUITABILITY OF SELECTED VEGETATION FOR SLURRY FILTERING, CONTAMINANT REMOVAL, AND DEWATERING

This appendix provides a summary of plant species that have previously been determined to be of potential use in slurry filtering, contaminant removal, and dredged material desiccation. The information presented here has been condensed from an extensive review of the literature and from information compiled during field trips to the New Orleans, Charleston, Philadelphia, Chicago, Portland, and Los Angeles Districts of the Corps of Engineers. Table B1 simplifies the findings and provides a compact reference to a considerable amount of specific information. Table B2 describes the relative concentrations of contaminants that are denoted as low, medium, or high in Table B1. The terms poor, good, slow, medium, and rapid are used by the authors to subjectively indicate the suitability of a plant species to function in regeneration, slurry filtering, dewatering, and the rate of growth. The terms shallow and deep under root depth indicate generally less than 6 m (shallow) or more than 6 m (deep).

TABLE B1

SUITABILITY OF SELECTED VEGETATION FOR SLURRY FILTERING, CONTAMINANT REMOVAL, AN

GENUS, SPECIES	RANGE								ENVIRONMENT			STEM GROWTH		STEM STRUCTURE				ROOT STRUCTURE					ROOT DEPTH		GROWTH RATE			REPRODUCTION				REGENERATION		SLURRY FILTERING		TOLERANCE			
	NORTH ATLANTIC	SOUTH ATLANTIC	NORTH PACIFIC	SOUTH PACIFIC	NORTH CENTRAL	MID-CENTRAL	GULF COAST	pH	FRESH	BRACKISH	SALINE	ERECT	SPREADING	WOODY	HERBACEOUS	STEM HEIGHT (M)	STEM DIAMETER (CM)	FLOATING	SUBSTRATUM	TAP	FIBROUS	STOLONS, RHIZOMES	SHALLOW	DEEP	SLOW	MODERATE	RAPID	FLOWERS	SEED	VEGETATIVE	BULBS, TUBERS	POOR	GOOD	POOR	GOOD	OIL-GREASE	SULFUR	NITROGEN	PHOSPHORUS
Allenrolfea occidentalis				X				>7.5			X				X																						T		
Alternanthera philoxeroides		X					X	4.8-7.7	X	X			X	X	X	V	V	X	X		X	X	X				X			X			X	X				H	H
Arundinaria gigantea		X				X	X		X			X		X		8	6		X		X	X	X	?		X	X	W	X	X			X		X				
A. tecta		X					X		X			X		X		2	2		X		X	X	X	?		X	X		X	X			X		X				
Arundo donax		X		X		X	X		X			X		X		6	2		X		X	X	X	X		X	X		X	X			X		X				
Baccharis halimifolia	X	X					X		X	X	X	X	X	X		3	3		X	X	X		X			X	X	W	X			X		X	X				
Chrysothamnus spp.			X	X	X						X	X	X	X		2				X				X				Y											
Cyperus esculentus	X	X	X	X	X	X	X	3.8-7.5	X			X			X	0.5			X		X	X	X				X		X	X	X		X	X					
Distichlis spicata	X	X	X	X			X	4.1-8.0		X	X	X			X	0.1-0.6	0.2		X			X	X			X	X		X	X			X	?					
Eichornia crassipes		X		X			X		X				X		X	1.2		X			X	X	X				X	W-V	X	X			X		X			H	H
Eucalyptus spp.				X			X		X	X	X	X		X		20	40		X	X	X		X			X			X			X							
Iva frutescens	?	X					X	4.0-7.2	X	X	X	X	X	X		3	3		X	X	X		X			X	X	Y-G	X				X		X				
Juncus effusus	X	X	X	X	X	X	X	4.0-5.9	X			X			X	1.8	0.5		X		X	X	X				X		X	X			X		X	T		M	H
J. roemerianus	?	X					X	4.0-7.1	X	X	X	X			X	2	0.5		X		X	X	X				X		X	X			X		X	T		M	M
Jussiaea spp.		X				X	X	4.9-5.8	X			X	X	X	X	2		X	X		X	X	X			X	X	Y	X	X			X		X				
Justicia americana	X	X			X	X	X		X				X		X				X		X	X					X		X		X		X	X				H	M
Lemna spp.	X	X	X	X	X	X	X		X				X		X			X			X		X				X		X	X			X	X				H	H
Medicago sativa	X	X	X	X	X	X	X	>6.0	X	X	X		X		X					X				X				Y	X										
Myriophyllum spp.	X	X	X	X	X	X	X	>7.0	X			X	X		X	1		X	X		X		X				X		X	X			X	X					
M. spicatum	X	X	X	X	X	X	X	>7.0'	X	X		X	X		X			X	X		X		X				X		X	X			X	X			T	H	H
Panicum virgatum	X	X	X	X	X	X	X	4.5-7.5	X	X		X		X	X	3	0.5		X		X	X	X				X		X	X			X		X				
Phragmites communis	X	X	X	X	X	X	X	3.7-8.0	X	X		X		X		4.5	4		X		X	X	X	X			X		X	X			X		X			M	
Phyllostachys spp.		X		X			X		X			X		X					X		X		X	?			X		X	X			X		X				
Pistia stratiotes		X					X		X				X		X	0.6		X			X	X	X				X			X			X		X				
Populus spp.	X	X	X	X	X	X	X		X			X		X					X	X	X					X	X		X				X	X					
P. deltoides	X	X	X	X	X	X	X		X			X		X					X	X	X					X	X		X				X	X					
P. heterophylla	X	X				X	X		X	?		X		X		25	75		X	X	X			X	X	X			X				X	X					
P. tacamahaca	X				X				X	?		X		X		30	180		X	X	X			X	X	X			X				X	X					
P. trichocarpa	X		X	X	X				X	?		X		X		10-30	75		X	X	X			X	X	X			X				X	X					
Potamogeton spp. (diversifolius, illinoensis, nodosus, pectinatus)	X	X	X	X	X	X	X		X			X	X		X	3.7		X	X		X	X	X				X		X	X			?'	X				?	L
Potamogeton spp. (foliosus, pusillus)	X	X	X	X	X	X	X		X	X		X	X		X	1		X	X		X	X	X				X		X	X			?	X					
Pseudosasa japonica	X	X	X	X			X		X			X		X					X		X	X	X	?			X		X	X			X		X				
Sagittaria latifolia	X	X	X	X	X	X	X	4.3-5.9	X	X		X			X	1.2			X		X	X	X		X	X		W	X	X	X		X	X				H	H
Salicornia spp.	X	X		X			X	4.7-8.5			X		X		X				X										X	X			?		?	T			
Salix spp.	X	X	X	X	X	X	X	4.7-7.5	X			X		X		15	V		X	X	X		X	X		X	X		X	X			X		X	?			
Sarcobatus spp.			X	X							X			X						X				X												?	T		
Scirpus americanus	X	X	X	X	X	X	X	6.7-7.8	X	X		X			X	1	0.6		X		X	X	X				X							X		?		M	M
S. acutus	X		X	X	X	X			X	X		X			X	1	0.6		X		X	X	X				X		X	X			?	X		?			
S. olneyi	X	X	X	X		X	X	3.7-6.9	?	X		X			X	1.2	0.6		X		X	X	X				X		X	X			?	X		T			
S. robustus	X	X		X			X	4.0-6.9	?	X		X			X	1.5	1		X		X	X	X				X		X	X			X	X		?			
S. validus	X	X	X	X	X	X	X	5.3-5.8	X			X			X	2	1		X		X	X	X				X		X	X			?		X	?			
Spartina alterniflora	X	X					X	4.5-8.5		X	X	X			X	2.5	1		X		X	X	X				X		X	X			X		X	S		L	L
S. cynosuroides	X	X					X	4.3-6.9	X	X	X	X			X	3	2		X		X	X	X				X		X	X			X		X	S		L	L
S. foliosus				X						X	X	X			X	1.2	1		X		X	X	X				X		X	X			?		X				
S. patens	X	X			X		X	3.7-7.9		X	X	X			X	<1	0.5		X		X	X	X				X		X	X			X		X	S		L	M
S. pectinata	X		X		X	X			X	X		X			X	2			X		X	X	X				X		X	X			?		X				
Spirodela spp.	X	X	X	X	X	X	X		X				X		X			X			X		X				X		X	X			X	X		?			H
Tamarix spp. (gallica)		X		X			X		X	X	X	X	X	X		5	8		X	X	X		X	X			X		X			X			X	?			
Typha spp.	X	X	X	X	X	X	X	3.7-8.5	X	X		X			X	3.7	V		X		X	X	X	?			X		X	X			X		X	?		H	H
Zizaniopsis miliacea		X				X	X	4.3-6.0	X			X			X	3.7	1		X		X	X	X			X	X		X	X			X		X	?		M	M

ANT REMOVAL, AND DEWATERING

URRY FIL-RING	CONTAMINANT													DEWA-TERING			VALUE POTENTIAL				
	TOLERANCE		REMOVAL																		
GOOD	OIL-GREASE	SULFUR	NITROGEN	PHOSPHORUS	IRON	MANGANESE	ZINC	COPPER	LEAD	NICKEL	CADMIUM	CHROMIUM	MERCURY	POOR	GOOD	CHEMICAL CONTROL	COMMERCIAL	AESTHETIC	WILDLIFE SUPPORT	NEGATIVE (LIST 1 to 5)	REMARKS
		T													X			?	?		
			H	H	M	M	M	H	M	M	M	L	?		X	L,M,P	A	B	C,F	5	
X															X		A,H	B	A		Controlled by continuous grazing or cutting
X															X		A,H	B	A		
X															X			B	A		
X															X	Q,R,S,T		A	A,F		
														X					A		
															X		G,I		D		
					L										X				B		
X			H	H	M	H	M	M	M	M	M	L	?		X	L,O	A	A		5	Can clog waterways if not controlled
															X	A	B	B	A		
X														?		B,E		A	A	4	
X	T		M	H										X		B,E			A	3	
X	T		M	M	L	L	L	L	?	?	?	?	?	X		B,C,E,F			A		
X														X		L,O,B,F		A			
			H	M	M	M	H	H	L	M	L	L	?	X						5	
			H	H	H	H	H	M	?	?	?	?	?	X		J	A		F		May inhibit mosquito breeding
															X		A		B		Does not thrive on poorly drained soil
														X		K,L,O			F	5	Can clog waterways if not controlled
		T	H	H	H	H	M	H	M	L	L	M	H	X					F	5	Can clog waterways if not controlled
X															X	I,H	A		A,B		
X			M		L	M	M	L	?	?	?	?	?		X	I	A	B	A,C	5	
X															X			B	A		
X														X		B,D,F,G Q,R,S,T		B	F	3	
														?	?	B,D,F,G	C	B	A		
														?	?	B,D,F,G	C	B	A		
														?	?	B,D,F,G	C	B	A		
														?	?	B,D,F,G	C	B	A		
														?	?	B,D,F,G	C	B	A		
			?	L	M	H	M	M	?	?	?	?	?	?		J,K,L,M N,O,P	A		B,F		
														?		J,K,L,M N,O,P			B,F		
X															X			B	?		
			H	H	M	M	M	[illegible]	?	?	?	?	?	?				A	B,D		
?	T													?			I				
X	?														X	Q,R,S,T	D,F	B	A,F		
	?	T												X		-				1	Poisonous-oxalate
	?		M	M										X		I					Cool desert plant
	?													X		I		B	A,B,C		
	T													X		I		B	C		
	?													X		I		B	A,B,C		
X	?													X		I		B	C		
X	S		L	L	L	L	L	L	?	?	?	?	?		X				A,B,E		
X	S		L	L	L	L	L	L	?	?	?	?	?		X				A,B,C		
X															X						
X	S		L	M	L	M	L	L	?	?	?	?	?		X		A		A,C,F		
X															X				?		
	?			H	H	H	H	M	?	?	?	?	?			J	A		F		
X	?														X	L,M,N,P	E,F			2	
X	?		H	H	L	H	M	M	?	?	?	?	?		X	I,B,D G,F		B	A,E	3	
X	?		M	M	M	M	M	M	L	L	L	M	?		X		A	B	A,C	3	

KEY

STEM STRUCTURE

V Variable

REPRODUCTION

Flowers:
- W White
- Y Yellow
- W-V Violet
- Y-G Yellow-Green

CONTAMINANT

- T Tolerant
- S Susceptible
- L Low
- M Medium
- H High

CHEMICAL CONTROL

- A. AMS — Ammonium sulfamate
- B. 2,4-D — 2,4-dichlorophenoxyacetic acid
  - C. AOHM — Alkanolamine salt
  - D. BEE — Butoxy ethanol ester
  - E. DMS — Dimethylamine salt
  - F. IOE — Iso-octyl ester
  - G. PGBEE — Propylene glycol butyl ether ester
- H. Dacthal — Dimethyl ester of tetrachloroterephtalic acid
- I. Dalapon — Sodium salt of 2,2-dichloropropionic acid
- J. Diquat — 1,1'-ethylene-2,2'-dipyridinium dibromide
- K. Endothall — 1,2-dicarboxy-3,6-endoxocyclohexane
- L. Silvex — 2-(2,4,5-trichlorophenoxy) propionic acid
  - M. BEE — Butoxy ethanol ester
  - N. IOE — Iso-octyl ester
  - O. K Salt — Potassium salt
  - P. PGBEE — Propylene glycol butyl ether ester
- Q. 2,4,5-T — 2,4,5-trichlorophenoxyacetic acid
  - R. BEE — Butoxy ethanol ester
  - S. IOE — Iso-octyl ester
  - T. PGBEE — Propylene glycol butyl ether ester

VALUE POTENTIAL

Commercial:
- A. Forage
- B. Furniture
- C. Lumber
- D. Basket Weaving
- E. Fenceposts
- F. Honey
- G. Coffee Substitute
- H. Fishing Poles
- I. Edible

Aesthetic:
- A. Pretty Flowers
- B. Pleasant Appearance

Wildlife Support:
- A. Shelter - Nesting, Roosting
- B. Food - Seed
- C. Food - Rhizomes
- D. Food - Tubers
- E. Food - Rootstock
- F. Food - Foliage

Negative:
1. Poisonous
2. Profuse lightweight seed producer - potential weed spreader
3. Harbors mosquitos and enhances mosquito population
4. Attracts insects - aphids, ants
5. Hard to control growth

? Inferred from literature or questionable

Table B2

Relative Concentrations of Contaminants

Denoting Categories

Contaminant	Level of Contaminant,* ppm		
	Low	Medium	High
Nitrogen	<10,000	10,000-20,000	>20,000
Phosphorus	<1,000	1,000-2,000	>2,000
Iron	<1,000	1,000-2,000	>2,000
Manganese	<200	200-1,000	>1,000
Zinc	<30	30-200	>200
Copper	<20	20-50	>50
Lead	<15	15-55	>55
Nickel	<20	20-40	>40
Cadmium	<10	10-20	>20
Chromium	<25	25-75	>75
Mercury	<10	10-200	>200

* The authors arbitrarily grouped the available information into the above categories.

APPENDIX C: USE OF VEGETATION FOR SLURRY FILTERING

Statement of the Problem

1. Confined land disposal areas for dredged material are primarily filled with hydraulically transported sediments, which are pumped directly from the dredging site or from hopper dredges. Large volumes of water are transported along with the sediment. Frequently within the disposal area, the water-to-sediment ratio of incoming material is in excess of 5 to 1 on a mass basis, resulting in a drastic disturbance of the original soil-water regime. Degradation of water quality invariably occurs when the water passing over outlet weirs from the containment area is contaminated. Although qualitative standards for effluent have not yet been imposed by Federal agencies, local and State standards are continually becoming more stringent. Standards for turbidity of the effluent followed by various CE Districts in 1974 are summarized in Table C1.[16*] The parameters of measurement vary widely and include: (a) density, g/ℓ; (b) turbidity, light transmission in Jackson Turbidity Units (JTU's); (c) settleable solids, ppm; or (d) settleability of solids, g/ℓ/hr.

Turbidity

2. Turbidity is a term commonly used to describe the presence of materials that affect light transmission through a liquid medium.[91,92] Turbidity of the effluent from dredged material disposal sites can be reduced by impeding the velocity of water flowing through the containment area. Vegetation within a disposal site would reduce water velocity by the interaction of the hydraulic load with leaves, stems, and roots of the plants, resulting in the dispersion of the energy. This dispersion effect should decrease channeling and promote a more even distribution of the finer settleable solids within the containment area. Vegetation should also diminish agitation of the slurry by wind action.

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* Raised numbers refer to similarly numbered items in the References at the end of the main text.

Table C1

Turbidity Standards for Effluent from Dredged Material Disposal Areas[16]

District	Effluent Standard Used*	District	Effluent Standard Used*
Detroit	8 g/ℓ above ambient	Seattle	5 to 10 JTU's
Galveston	↓	Portland	5 JTU's
New York	↓	Buffalo	50 ppm settleable solids
Philadelphia	↓		
Sacramento	↓		
Norfolk	13 g/ℓ above ambient	Charleston	None set
Jacksonville	50 JTU's	Chicago	↓
Wilmington	50 JTU's	Mobile	↓
		New Orleans	↓
		Savannah	↓

* New criteria are presently being developed.

Foams, surface films, and emulsions

3. Foams result from the presence of chemicals, usually organic compounds, that lower the surface tension of water. Oil and grease films indicate the presence of organic molecules that are immiscible in and less dense than water. Often immiscible films become dispersed in the aqueous phase as small particles forming an emulsion upon agitation. The formation and stability of emulsions are partially dependent on the presence of foam-forming chemicals, termed "emulsifying agents."[93]

Chemical factors affecting water quality and color

4. The presence of abiotic dissolved and particulate substances in dredged material slurry water represents a potential for contamination of adjacent waterways because ionic materials can be carried from containment sites by adsorption onto or within such vehicles. Excessive foam and surface films may impede oxygen diffusion into the water, thereby promoting stagnation as the biological oxygen demand within the containment area increases.[94] Sediment that becomes disturbed during dredging frequently undergoes color changes associated with changes in the redox state of elemental constituents. By altering patterns of light absorption and reflection, these colored substances directly affect water color.

Vegetation and dredged material interactions

5. Dredging operations were observed by the authors at four sites within the New Orleans, Charleston, Philadelphia, and Portland Districts. Additional information was obtained from consultants, District personnel, and other individuals associated with dredging operations involving areas of confined disposal.

6. Most contractors or District personnel agreed that the presence of thick vegetation growing on a disposal site helps to decrease the turbidity of the effluent. Based upon observations, discussions, and the literature, it is believed that vegetation will accentuate the removal of cohesive silt and clay-size particles from dredged material slurry. The fine organic fraction, which has an affinity for

these inorganic particles,[95] should also be removed. Very coarse dredged material should settle out with little difficulty in properly constructed containment areas.

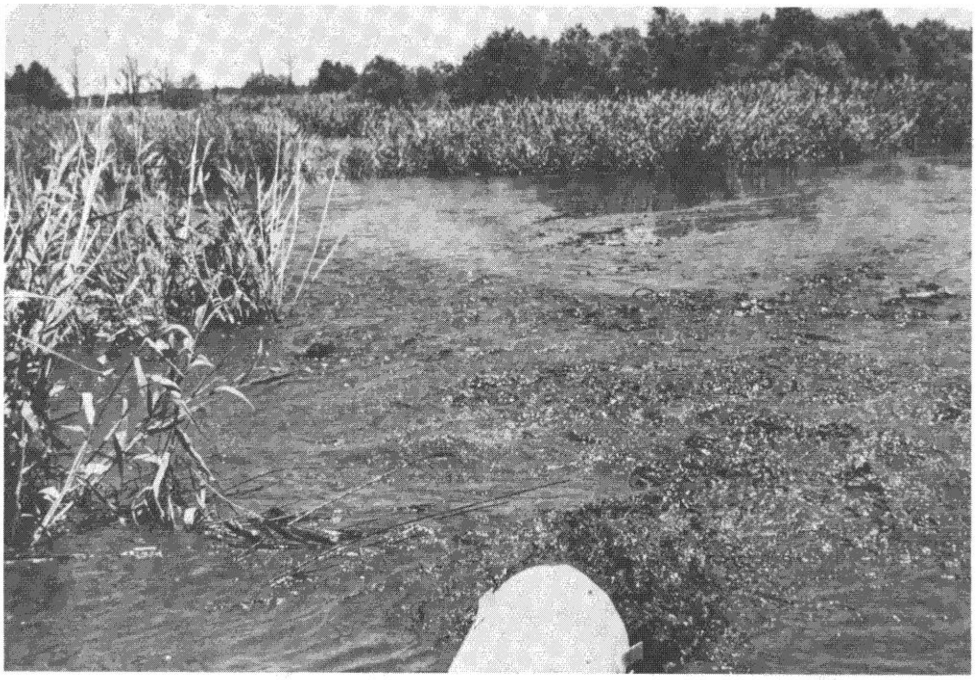
7. Silt, surface oil films, and foams are removed from the slurry by the physical presence of the plants. The clay and other fine-sized particles are likely removed from suspension by chemical changes related to the presence of vegetation. Flocculation induced by plant exudates may be the prime mechanism in the removal of finer substances, although there is little direct evidence available in the literature to support this hypothesis. It is concluded that slurry filtering is promoted by a combination of physical and biochemical phenomena, induced by the liberation of organic compounds by the vegetation and accentuated by the physical filtration and resultant accumulation of solids on the surface of the plants.

Present Function of Vegetation in Dredged Material Containment Areas

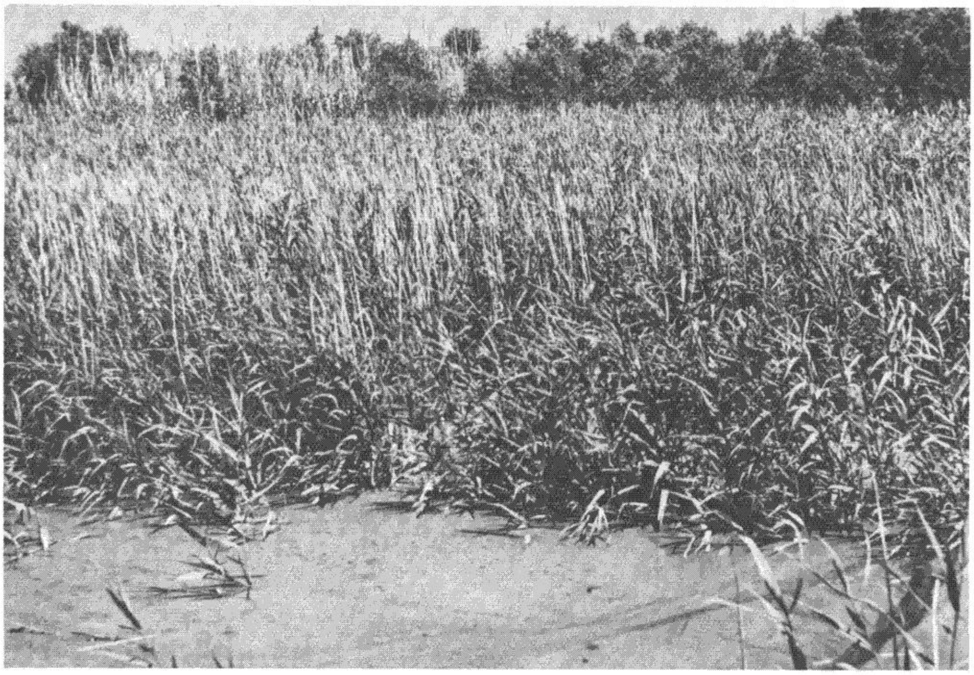
Freshwater and brackish water sites

8. There are several species of naturally occurring plants that have been noted to aid in the filtration of dredged material slurry. At many diked brackish and freshwater disposal sites in the Philadelphia and Charleston Districts, the common reed grass, *Phragmites communis*, formed pure stands, which attained an average height of more than 3 m. Its remarkable regenerative ability after complete burial beneath 2 m of dredged material makes it a prime plant for slurry filtering. Edwards[64] confirmed the positive effect of *Phragmites* on sediment deposition and its general tolerance of various types of substrata.

9. At Waccamaw Point, east of Georgetown, South Carolina, the authors observed freshwater disposal operations at a site dominated by natural stands of *P. communis*, giant reed grass (*Arundo donax*), and willow (*Salix* spp.) (Figure C1). The turbidity of the effluent was similar to that of the river into which it was discharged after passage through approximately 500 m of vegetation in a 20-ha diked area. At the Killcohook site in the Philadelphia District, where sediments from



a. Discharge into a natural stand of P. communis and Salix spp.



b. Slurry flowing through P. communis

Figure C1. Use of Phragmites communis in filtering dredged material slurry at the Waccamaw Point disposal site, Georgetown, South Carolina brackish water were being dredged from the upper Chesapeake Bay area, the authors observed negligible turbidity after passage of the slurry through a stand of P. communis having an area of approximately 200 ha (Figure C2).

Figure C2. Clean discharge water leaving a P. communis-dominated disposal site, Pennsville, New Jersey

10. Several brackish and freshwater species observed by authors to have considerable value as filtering agents at disposal sites in the New Orleans District were groundsel bush (Baccharis halimifolia), marsh elder (Iva frutescens), willow (Salix spp.), Black rush (Juncus roemerianus), and bulrush (Scirpus spp.).

11. The capacity of several species of Salix to filter fine-textured dredged material obtained from the lower Willamette River at Portland, Oregon, was noted. Vegetation was considered to be of lesser value as a filtering agent on sandy-textured dredged material from the lower Columbia River in the same District. Both Salix spp. and cottonwood (Populus spp.) have amazing regenerative powers. At dredged material disposal sites in the Chicago District, these plants were able to survive the accumulation of up to 6 m of sediment.

Brackish water and saline sites

12. Dredged material of high salinity, in most cases, can be colonized only by salt-tolerant vegetation. The sediments of marine areas are typically quite saline. The salinity of brackish water sediments, generally less than that of marine, is often increased through evaporation following deposition in containment areas. Salt-tolerant Juncus roemerianus and Spartina alterniflora have been noted to aid in filtering the dredged material slurry in containment areas constructed within the New Orleans District. These sturdy plants often exceed 1 m in height and form dense stands.[35,51] Spartina alterniflora has been particularly valuable for its ability to stabilize tidal marshes and dredged material,[18,85] although its capacity to regenerate following deep burial is not exceptional.[35] Most species of Spartina grow rapidly with yields of S. alterniflora ranging from 500-g m^{-2} yr^{-1} in the north Atlantic[82] to over 1400-g m^{-2} yr^{-1} in gulf coast marshes.[78]

Design Criteria for Uses of Vegetation

13. The Corps of Engineers has conventionally used filters to reduce the turbidity of the effluent from dredged material containment areas. The main problem with filters has been clogging, thus impeding drainage from the disposal sites.[16] Considering a vegetative community as a macrofilter, the pore size (i.e. distance between plants) is large; thus there is little chance of clogging such a filtering system. In spite of the large pore size, because of the large surface area involved,

the filtering capacity of a vegetative community would be considerably greater than that of a conventional filter.

14. For the purpose of slurry filtering, vegetation should be established in areas sufficiently distant from discharge lines so that the plants are not subjected to great accumulations of sediments.[16] Three types of vegetative associations are recommended for filtering dredged material slurries: (a) those consisting of plants that strongly anchor themselves to the substratum; (b) those consisting of plants that float at the surface of the water; and (c) those consisting of a combination of the two types. Totally submerged vegetation will not be considered useful because turbid waters will prevent light from reaching the photosynthesizing surfaces of the plants.[96]

Attached vegetation

15. In order to be most effective as filtering agents in a containment area, attached plant species should possess the following characteristics: (a) tall sturdy stems that are resistant to damage; (b) strongly anchoring root and/or rhizomal systems; and (c) dense stem and leaf growth with maximum filterable surface of plant tissue per substratum surface area. Attributes that would favor regeneration of attached plant species following burial beneath dredged material include: (a) rapid horizontal and vertical development of roots and rhizomes; (b) development of adventitious roots from buried aerial parts (e.g., stems); (c) rapid growth and elongation of new and old shoots; (d) presence of root storage organs (e.g., bulbs or tubers); and (e) the ability to survive anaerobically for variable periods of time.

16. Perennial plant species possessing the aforementioned vegetative and regenerative characteristics are: water willow (*Justica americana*); cottonwood (*Populus deltoides*); willow (*Salix nigra*); saltcedar (*Tamarix gallica*); marsh elder (*Iva frutescens*); *Phragmites* spp.; and *Arundo* spp. among others.

17. If regenerative ability is not a criterion, then nearly any thick stand of vegetation may be used as a filtering agent during dredged material disposal. Several rapidly growing annual species can serve this purpose, although perennial species are less likely to

be dislodged as readily as the annuals.

Floating vegetation

18. Floating vegetation may be useful to filter dredged material slurries where the accumulation of sediment becomes excessive, resulting in dislodgement or burial of attached plant species. Floating vegetation may be more appropriate in diked areas where increasing water depth limits the survival of rooted species. It is important to note, however, that floating plants are essentially limited to fresh and mildly brackish water.

19. Floating plant species, in order to be most effective as filtering agents, should possess the following characteristics: (a) the plants should be massive enough so as not to be washed over the outlet weir and (b) the root system should be well developed to maximize removal of nutrients and contaminants from the slurry water. Eichornia crassipes and Pistia stratioites possess characteristics that suit them well as filtering agents in dredged material containment areas.

Designs for Use of Vegetation in Disposal Areas

20. The perimeter of confined dredged material disposal areas is often congruous with the shape of the purchased or leased land parcel. These areas are in some cases divided into smaller parcels by cross dikes or retaining dikes; others are partially divided by spur dikes, which increase the slurry flow distance within the confinement. This compartmentalization of a disposal site produces a variety of situations for the use of vegetation.

21. The combination of attached and floating vegetation may be an effective approach to slurry filtering in many disposal areas where the two types could be propagated collectively or individually (Figures C3-C5). The arrangement of species within a containment area should be done with full knowledge of physical and chemical factors potentially limiting the effectiveness of the vegetative filtering components. Tall sturdy vegetation, including Phragmites spp., would retain coarser materials. Less sturdy vegetation with a large surface area, such as

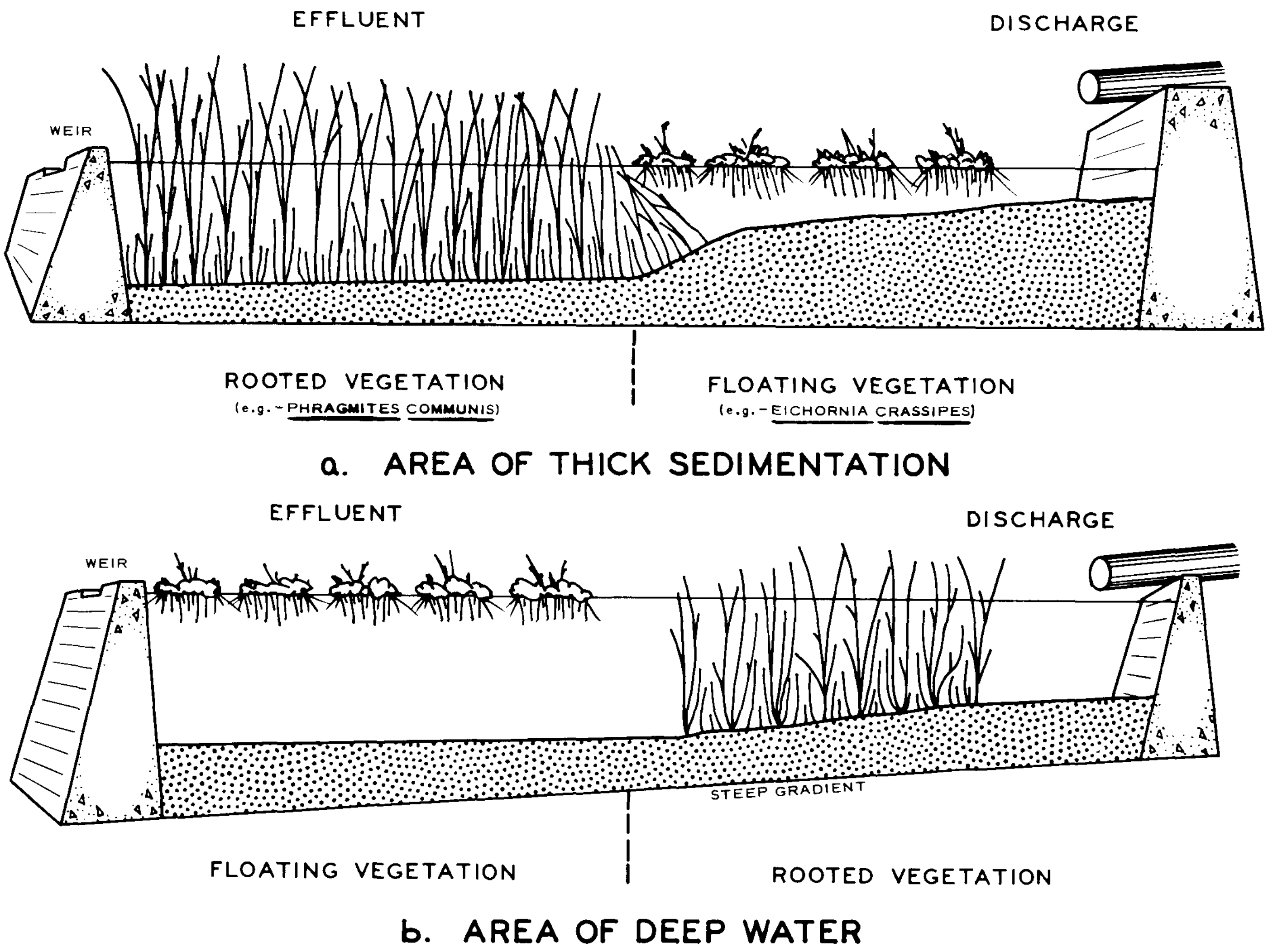
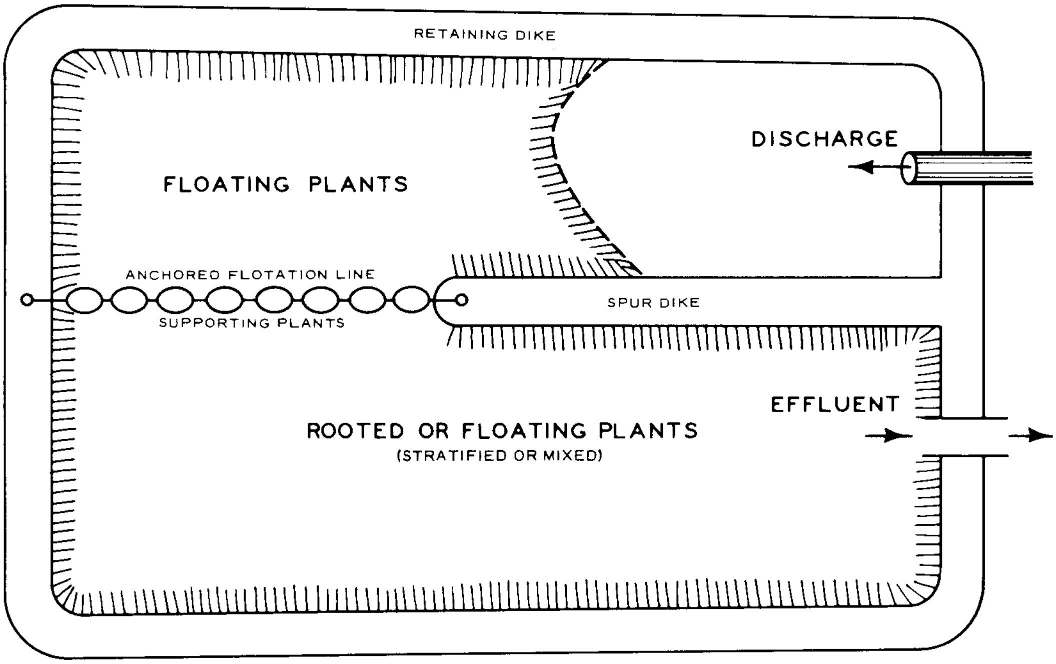
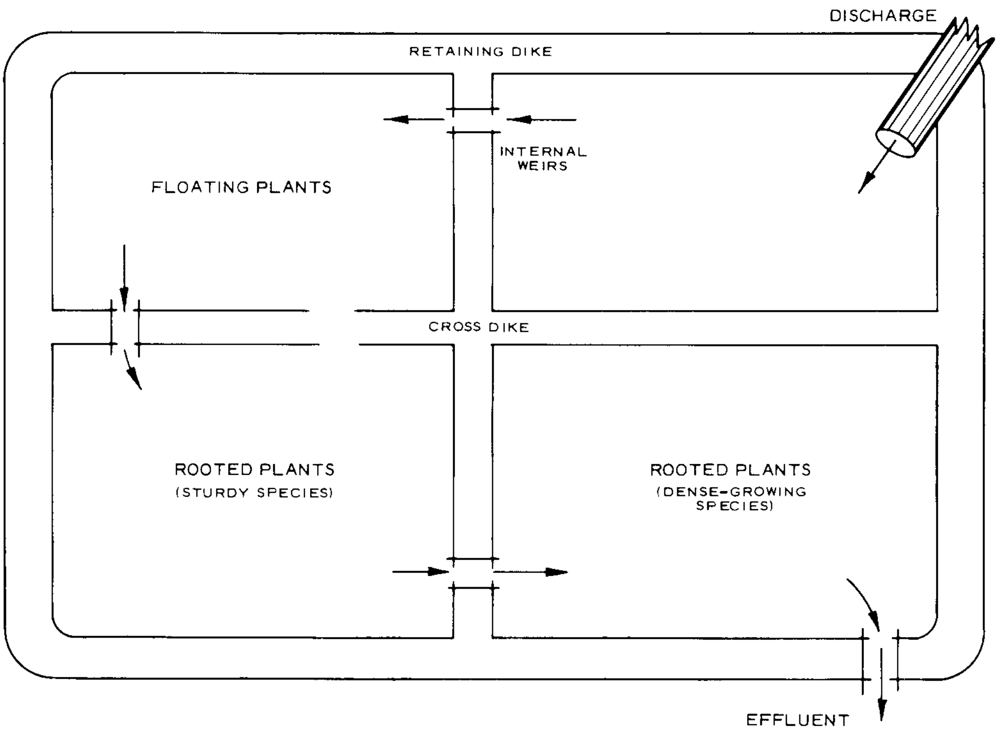


Figure C3. Hypothetical utilization of combinations of attached and floating vegetation in disposal areas

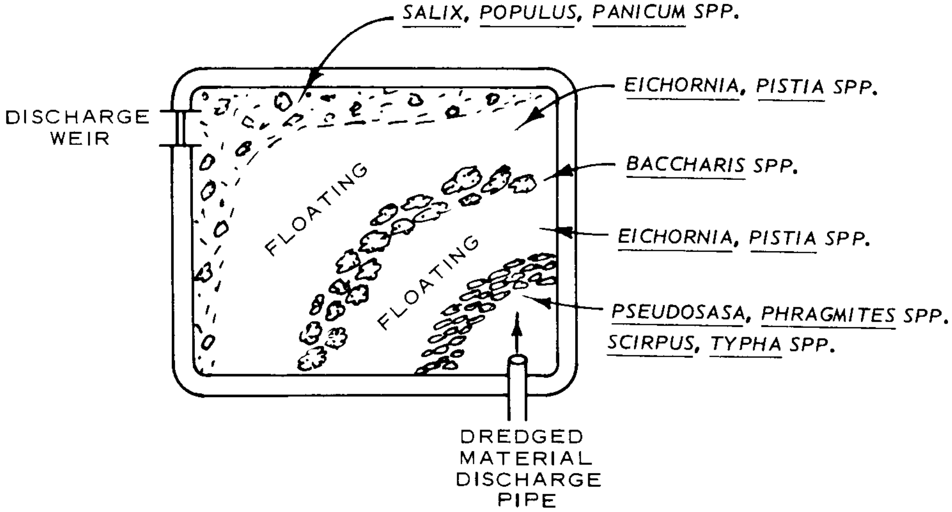


a. Spur-diked area

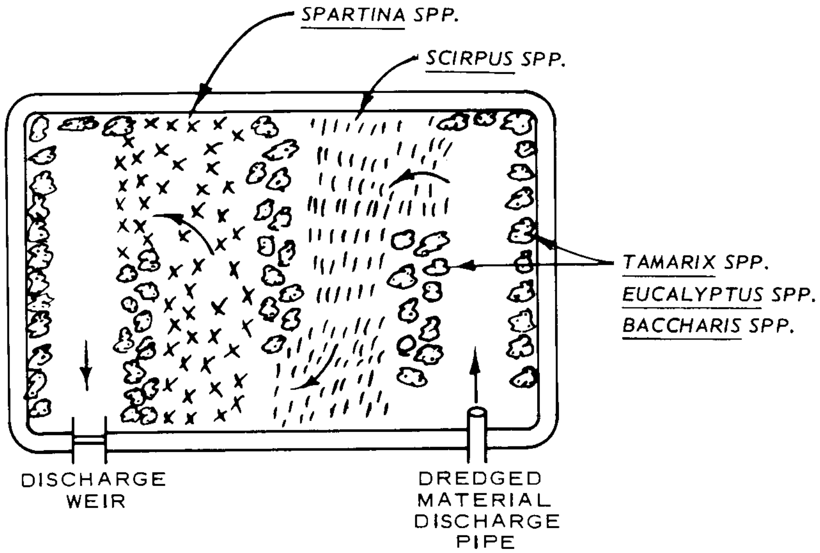


b. Cross-diked area

Figure C4. Examples of vegetation used in spur- and cross-diked areas



a. Freshwater vegetation



b. Brackish-saltwater vegetation

Figure C5. Landscaping with freshwater or salt-tolerant vegetation for slurry filtering

Panicum virgatum or Phalaris arundinacea, can be grown behind the coarser vegetation to retain finer sediments. Figure C5 indicates ways vegetation might be arranged in confined disposal areas. The grasses named therein are noted for their ability to remove nutrients; these might also serve as a harvestable forage crop, depending on quality of the dredged material.

22. The arrangement of vegetation into distinct zones could be useful in promoting differential sedimentation and preventing erosion. For example, rows of vegetation oriented parallel to the direction of current flow would create shoaling in these areas. Such a design would be of economic value in preventing short circuiting of the slurry between the discharge line and the sluice. Vegetation growing along the margins of the dikes would also prevent bank erosion while giving them added strength.

23. A combination of plant species was recently employed in Ocala, Florida, for the purification of wastewater (personal communication, Mr. Lawrence Banks, Biological Water Purification, Inc.). In this system, Phragmites spp. was used to filter out the solids while Scirpus spp. removed dissolved pollutants and bacteria. Species of Iris and Sambucus also appeared to be capable of reducing the number of microbial pathogens in water. This example typifies the selectivity provided by different species of vegetation for both physical and biochemical purposes.

24. A summary of the plant species existing at disposal sites observed in this study is given in Table C2. The authors suggest that many of these species may be of value in reducing the turbidity of dredged material slurries. Based on field observations and a literature survey, a larger list of species, those that are considered to have potential in filtering dredged material, was compiled. This list, including some characteristics of each species, is given in Appendix B.

25. Various types of interactions are possible as a dredged material slurry moves across a vegetated confined disposal site. The information provided in the foregoing paragraphs is presented in order to make evident the complexity of some of these interactions that may

Table C2

Vegetation of Exceptional Value for Dredged Material Slurry Filtering

Category	Types of Vegetation
Attached vegetation - salt water	*Eucalyptus* spp. (*E. botryoides*, *E. globulus*, *E. miltriflora*, *E. umbellata*)*
	Juncus spp. (*J. roemerianus*)
	Scirpus robustus
	Spartina alterniflora
	Spartina cynosuroides
	Spartina foliosus
Attached vegetation - brackish water	*Baccharis halimifolia*
	Eucalyptus spp.
	Iva frutescens
	Juncus spp.
	Panicum virgatum
	Phalaris arundinacea
	Phragmites communis
	Salix spp.
	Scirpus spp. (*S. olneyi*, *S. robustus*)
	Spartina cynosuroides
	Tamarix spp. (*T. gallica*)
	Typha angustifolia
Attached vegetation - fresh water	*Arundinaria gigantea*
	Arundo donax
	Jussiaea spp.
	Panicum spp. (*P. virgatum*)
	Phalaris arundinacea
	Phragmites communis
	Phyllostachys spp.
	Populus spp.
	Pseudosasa japonica
	Salix spp.
	Scirpus spp. (*S. validus*, *S. californicus*)
	Tamarix spp.
	Typha spp. (*T. latifolia*)
	Zizaniopsis miliacea
Floating vegetation - fresh water	*Eichornia crassipes*
	Pistia stratioites

* Personal communication, Dr. Robert H. Chabreck, School of Forestry and Wildlife Management, Louisiana State University, Baton Rouge.

occur, not to define specifically what <u>will</u> occur. Field observations will provide the best means of studying the value of vegetation in slurry filtering, since vegetative response is subject to an array of site-specific variables that are difficult to simulate under laboratory conditions.

APPENDIX D: CONTAMINANT REMOVAL BY VEGETATION

Contamination Status of Dredged Material

1. Each year the Nation's waterways and harbors accumulate materials from a variety of different sources. The composition of the sediment accumulated in waterways and harbors depends to a large extent on the sources contributing materials into them. One of the major contributing sources is the runoff of materials from land surfaces after rainfall. Rainfall, when causing erosion, transports materials that have adsorbed to the surface of soil particles and delivers these materials into streams, rivers, and lakes. Industrialization and the increased density of population along navigable waterways have altered the physical and chemical nature of many watersheds, resulting in the contamination of some harbors and channels.

Heavy metals

2. A number of sediments from rivers, harbors, and bays throughout this Nation and in Canada have been reported to contain various concentrations of heavy metals.[97-99*] Table D1 lists the concentrations of certain elements at levels naturally occurring in the Earth's crust and at levels measured from selected regional locations. The regional locations are presented here to emphasize that there are areas in which sediments contain heavy metals that have accumulated to levels above those naturally occurring in the Earth's crust. Depending upon local standards, some of these sediments may not be allowed to be discharged into open water because of their potentially contaminating influence.

3. Much of the data published on the heavy metal content of sediments are based on either acid extractable procedures[98,99] or on acid digestion techniques for total content of heavy metals.[97,100] The potential for a heavy metal to become a contaminant depends on its

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* Raised numbers refer to similarly numbered items in the References at the end of the main text.

Table D1

Element Concentrations in the Earth's Crust and in Various Waterway Sediments

Element	Earth's* Crust mg/kg	Location: Sediment, mg/kg			
		Baltimore** Harbor	Mobile† Bay	Calumet†† River	Portland‡ Harbor
Nitrogen (N)	2,500	2,872	-	3,683	21
Iron (Fe)	50,000	-	31,000	-	-
Aluminum (Al)	81,000	-	-	-	-
Phosphorus (P)	1,200	-	-	45	-
Manganese (Mn)	1,000	739	-	-	-
Sulfur (S)	520	-	-	1,657	4
Chromium (Cr)	200	492	-	41	-
Nickel (Ni)	100	36	-	43	-
Zinc (Zn)	80	888	120	1,943	-
Copper (Cu)	70	342	16	112	-
Lead (Pb)	16	346	23	576	-
Mercury (Hg)	0.5	1.2	0.4	159	1.3
Cadmium (Cd)	0.2	6.6	2.6	10	-

* Reference 95.
** Personal communication from Mr. Gary Loew, Baltimore District.
† Reference 97.
†† Personal communication from Mr. Bernie Bochantin, Chicago District.
‡ Personal communication from Mr. Charles Galloway, Portland District.

availability rather than its total concentration within a sediment. In general, heavy metals in an insoluble form are unavailable for biological uptake and thus are unlikely to be concentrated in food webs. Many heavy metals, however, readily change solubility with varying redox potential and are influenced by association with those organic and inorganic compounds which promote their solubility.

Nitrogen and phosphorus

4. Amounts of nitrogen and phosphorus found in sediments vary widely, depending on the kind and quantity of contributing material. Examples of nitrogen and phosphorus contents reported in sediments are shown in Table D1. The most predominant form of nitrogen in inorganic sediments is ammonium nitrogen; however, in organically enriched sediments, organic nitrogen predominates. Under oxidizing conditions, ammonium nitrogen and organic nitrogen (in part) are microbiologically oxidized to nitrate nitrogen. Both nitrate and ammonium sources of nitrogen are readily available for plant growth. In most sediments, phosphorus occurs as a phosphorus-solid complex.[101] Dredging and disposal operations cause an increase in suspended solids that, when containing high phosphorus concentrations, may contribute large amounts of dissolved phosphate to the discharge waters. Dissolved phosphate is readily available for plant growth.

5. Although nitrogen and phosphorus generally are not considered toxic contaminants, excesses of these elements in an available form produce rapid deterioration of water quality by enhancing eutrophication processes. It is suggested that certain vegetation can be used to remove ammonium nitrogen, nitrate nitrogen, and phosphorus from water flowing over a disposal site. This technique is discussed in detail on pages D5-D9.

Sulfur

6. Although sulfide, the reduced form of sulfur, can bind heavy metals under anaerobic conditions, sulfide complexes deteriorate under aerobic conditions and release heavy metal contaminants as the sulfide becomes oxidized to sulfate. Sulfate ions in contact with water form sulfuric acid and can change the pH of the substratum. Not only are

potential contaminants released in this process, but the soil often becomes too acid for successful colonization of plants.[102] Fleming and Alexander observed that sediments in a South Carolina tidal marsh developed high acidity when drained and allowed to oxidize.[103] These sediments contained up to 5.5 percent total sulfur, and when drained, sulfides were oxidized to sulfate with a resultant decrease in sediment pH from 6.4 to as low as 2.0. Similar sulfur acidity problems have been described for soils known as Katteklei (cat's clay) in Holland[104] and along the east coast of the United States.[105]

Oil and grease

7. The concentrations of oil and grease in sediments vary from a trace to very high, depending primarily on the extent of industrialization and the amount of traffic along the waterway. Contents of oil and grease in dredged material presently range from less than 1 mg/ℓ in parts of Portland Harbor to as much as 11,700 mg/ℓ in parts of Baltimore Harbor. (Personal communications from Mr. Charles Galloway, Portland District, and Mr. Gary Loew, Baltimore District, respectively.)

8. Oil and grease may adsorb to solids, or become emulsified[106] and remain in suspension after discharge of dredged material into a disposal site. Oil and grease, suspended in the emulsified state or in association with clay particles, tend to flow out of the disposal site in turbid discharge waters. As previously emphasized, the presence of vegetation in a disposal site prior to disposal operations can help to remove suspended oil and grease from effluent waters. Plant roots, rhizomes, stems, and leaves would physically retard the movement of oil and grease molecules and thus keep the oil and grease in the disposal area as the standing water is removed.

9. Numerous organisms are able to degrade oil and grease.[107-109] These hydrocarbon decomposers excrete large amounts of acids, alcohols, ketones, and other metabolites that are in turn metabolized by other decomposer groups.[108] The rate of decomposition of oil and grease depends largely on environmental conditions at the disposal site. For a microbial population to expand rapidly, it must be able to produce sufficient protein. Therefore, microbial growth and decomposition of oil

and grease may be limited by the availability of nutrients, especially nitrogen and phosphorus.[109]

10. Alexander indicates that microbial activity occurs most efficiently under aerobic conditions.[109] Naplekova et al. reported that manganese accelerates the decomposition of cellulose by cellulose-decomposing microorganisms.[110] The presence of manganese in dredged material may also enhance the decomposition of the oil-grease component of dredged material. Temperature is also an important factor in microbiological degradation of oil. In northern regions, cooler temperatures will slow the rate of oil decomposition, while in warmer southern climates, oil decomposition will be more rapid.

Pesticides and herbicides

11. Pesticides and herbicides are other organic contaminants that may accumulate in sediments through runoff into rivers and harbors. Most organic pesticides and herbicides undergo biological degradation in much the same manner as oil-grease components of dredged material.

Vegetative Uptake and Tolerance of Nutrients, Heavy Metal, and Other Contaminants

12. The nutrient removal capability of a given plant species depends primarily on the concentrations of nutrients in an available form within the environment. In general, absorption rates are proportional to and dependent upon the concentrations within the medium from which they are removed. The nutritional substratum for the growth of rooted plants is primarily the sediment, although significant amounts of nutrients can be removed from the water by the submersed leaves of many rooted plants. Nutrient removal by floating (nonrooted) plants is of necessity restricted to the aquatic medium.

13. Nutrient removal by a plant community, when considered on an areal basis, is primarily dependent upon the productivity of the community and secondarily on the density of plants within it. Although conceptually oversimplified, the measured yield of a plant community can be considered an index of its productive capacity.

14. Although some literature exists on the nutritional status

and uptake capabilities of various aquatic plants, relatively little information is available concerning the heavy metal content or the dynamics of heavy metal uptake by aquatic plants. There has been far more research published on the nutrient and heavy metal removal capabilities of various freshwater plants than for either brackish or saltwater marsh species. The nutrient and heavy metal contents of selected plant species are given in Table D2, while the nutrient removal capabilities of some of these species are presented in Table D3. Nutrient removal values in Table D3 are based on the stated yield of the plant community. Since information on the contents of nutrients and heavy metals in woody plant species is limited, this discussion largely concerns herbaceous plant species.

Nitrogen and phosphorus

15. Gosselink et al. determined the nutrient content of seven plant species of potential value as colonizers of disposal areas: *Spartina alterniflora*, *Distichlis spicata*, *Spartina patens*, *Juncus roemarianus*, *Spartina cynosuroides*, *Sagittaria falcata*, and *Phragmites communis*. These plants were analyzed after growth under natural conditions. Nitrogen and phosphorus contents were highest in *S. falcata*, a freshwater species, and *P. communis*, a brackish water species. Water hyacinths (*Eichornia crassipes*) demonstrate good potential for removing nitrogen and phosphorus from their environment.[46,47] Dunigan and Schamsuddin found that *E. crassipes* can take up large quantities of both ammonium nitrogen and nitrate nitrogen and somewhat lesser quantities of phosphorus.[46] Wahlquist observed a threefold increase in the growth of *E. crassipes* when fertilized with nitrogen and phosphorus.[47] Other freshwater plant species that are able to take up and contain relatively large amounts of nitrogen and phosphorus include alligator weed (*Alternanthera philoxeroides*), water willow (*Justicia americana*), and duckweeds (*Lemna* spp. and *Spirodela* spp.) (Table D2). Culley and Epps suggest that *Lemna* spp. and *Spirodela* spp. have high potential for use in wastewater treatment because of their rapid growth rate, ease of harvest, high nutritional value, high inorganic content, extended growing period, nontoxicity to animals, and lack of serious pests.[10]

16. The growth of some pondweed species (*Potamogeton* spp.) has

Table D2

Average Nutrient and Heavy Metal Contents of Selected Plant Species

Plant Species	Reference	Nutrient, ppm*						Heavy Metal, ppm**				
		N	P	Fe	Mn	Zn	Cu	Pb	Ni	Cd	Cr	Hg
					Freshwater							
Eichornia crassipes	27	21,230	5,226	2,683	1,912	210	43	52	38	16	21	--
	28	26,400	4,300	250	3,940	50	11	--	--	--	--	--
	45	--	4,250	--	--	--	--	--	--	--	--	--
Alternanthera philoxeroides	27	23,730	3,274	1,911	978	166	243	49	24	12	23	--
	28	28,700	3,200	720	440	90	15	--	--	--	--	--
	29	28,800	3,500	--	--	--	--	--	--	--	--	--
Justicia americana	27	26,720	2,495	1,306	684	134	147	14	23	4	24	
	28	20,200	1,200	1,085	112	265	26	--	--	--	--	--
	29	20,400	1,200	1,086	88	203	29	--	--	--	--	--
Myriophyllum spicatum	27	18,800	1,647	2,753	1,282	142	118	43	18	6	64	
	61	30,000	4,000	--	--	--	--	--	--	--	--	--
	12											243
Zizaniopsis miliacea	27	13,090	1,704	1,353	509	97	46	15	18	4	58	--
Sagittaria falcata	41	20,800	3,800	1,346	394	56	17	--	--	--	--	--
Sagittaria latifolia	71	--	580	--	1,985	78	43	--	--	--	--	--
Typha latifolia	71	--	230	625	2,575	60	26	--	--	--	--	--
	111	12,100	3,400	--	--	--	--	--	--	--	--	--
	28	13,700	2,100	120	412	30	37	--	--	--	--	--
	59	--	--	--	1,000	31	0.1	--	--	--	--	--
Lemna spp.	57	34,800	--	--	--	--	--	--	--	--	--	--
	58	--	--	--	4,030	--	25	--	--	--	--	--
	10	--	6,700	6,500	15,300	364	14	--	--	--	--	--
	59	--	--	--	1,100	22	20	--	--	--	--	--
Spirodela spp.	10	--	4,100	3,900	2,200	62	12	--	--	--	--	--
	59	--	--	--	4,820	960	--	--	--	--	--	--
Potamogeton spp.	71	--	458	1,000	1,790	99	27	--	--	--	--	--
Pistia stratioites	45	21,000	3,000	--	--	--	--	--	--	--	--	--
Juncus effusus	52	12,400	--	--	--	--	--	--	--	--	--	--
	53	13,300	2,000	--	--	--	--	--	--	--	--	--
Scirpus americanus	111	12,100	1,400	--	--	--	--	--	--	--	--	--
				Brackish Water								
Phragmites communis	41	13,300	1,600	95	61	33	10	--	--	--	--	--
	59	--	--	--	1,560	18	11	--	--	--	--	--
Spartina patens	41	7,300	1,000	90	220	17	6	--	--	--	--	--
Spartina cynosuroides	41	6,500	930	100	108	19	6	--	--	--	--	--
Myriophyllum spicatum	61	20,000	4,000	--	--	--	--	--	--	--	--	--
				Saltwater								
Spartina alterniflora	41	9,200	1,200	346	58	17	4	--	--	--	--	--
	85	6,750	850	313	23	11	2	--	--	--	--	--
Distichlis spicata	41	9,800	1,200	366	312	18	6	--	--	--	--	--
Juncus roemerianus	41	10,600	1,200	131	73	17	6	--	--	--	--	--

Note: Dash indicates no data available in reference.

* N, nitrogen; P, phosphorus; Fe, iron; Mn, manganese; Zn, zinc; Cu, copper.

** Pb, lead; Ni, nickel; Cd, cadmium; Cr, chromium; Hg, mercury.

Table D3

Average Nutrient and Heavy Metal Removal by Selected Plant Species

Plant Species	Reference	Nutrient* Removal, kg/ha						Heavy Metal** Removal, kg/ha				Dry Weight Yield, kg/ha
		N	P	Fe	Mn	Zn	Cu	Pb	Ni	Cd	Cr	
Freshwater Plants												
Eichornia crassipes	27	297	20	30.2	20.2	2.68	13.44	0.44	0.33	0.14	0.24	16,016
	28	1980	322	19.0	296.0	4.0	1.0	--	--	--	--	75,000
Alternanthera philoxeroides	27	381	43	21.3	13.4	2.35	15.90	1.12	0.44	0.16	0.40	17,360
	28	1779	198	45.0	27.0	6.0	1.0	--	--	--	--	--
	29	185	24	--	--	--	--	--	--	--	--	6,737
Justicia americana	27	179	76	4.5	3.4	1.12	0.67	0.22	0.22	0.02	0.12	3,360
	28	2293	136	123.0	13.0	30.0	3.0	--	--	--	--	--
	29	386	24	23.0	2.0	4.0	0.5	--	--	--	--	24,580
Myriophyllum spicatum	27	189	11	29.1	15.7	1.68	1.34	0.44	0.11	0.08	0.16	--
Zizaniopsis miliacea	27	114	11	12.3	6.0	0.67	0.56	0.11	0.11	0.06	0.40	3,472
Typha latifolia	28	2630	403	23.0	79.0	6.0	7.0	--	--	--	--	--
Saltwater Plants												
Spartina alterniflora	85	43	5	2.6	0.12	0.06	0.07	--	--	--	--	2,670

Note: Dash indicates no data available in reference.
* N, nitrogen; P, phosphorus; Fe, iron; Mn, manganese; Zn, zinc; Cu, copper.
** Pb, lead; Ni, nickel; Cd, cadmium; Cr, chromium.

been observed to respond drastically to the phosphorus concentration in the environment.[52] Potamogeton pectinatus demonstrated increased abundance as the total phosphate level rose from 0.1 to 0.6 ppm in the aquatic environment. Potamogeton richardsonii, however, was affected oppositely. Different responses to changes in the environment are common among species within many genera.

17. Brackish and saline-adapted plant species generally contained lower amounts of nitrogen and phosphorus than did freshwater species (Table D2), but, like freshwater species, some have responded very well to fertilization. Broome et al. found that the growth of marsh cord grass (Spartina alterniflora), when transplanted on sand-textured dredged material, improved after applications of additional nitrogen and phosphorus.[85]

18. The critical consideration regarding excess nitrogen and phosphorus in dredged material is the potential impact of these as eutrophicating agents, affecting waterways adjacent to disposal sites. It is suggested that selected vegetation could be used to remove nitrogen and phosphorus from disposal areas before the water is discharged into nearby waterways. As dredged material begins to dry, the vegetation would continue to remove nitrogen and phosphorus from the sediments.

Sulfur

19. The tissue concentration of sulfur is similar to that of phosphorus in most aquatic plants. Although sulfur, in its elemental or oxidized form, is not toxic to plants, the reduced form (sulfide) can be phytotoxic when it exists as hydrogen sulfide (H_2S). Even at low concentrations, H_2S is highly toxic to citrus roots.[112] Hydrogen sulfide toxicity is a common problem causing crop damage in the poorly drained rice fields of the Far East.[113] In disposal areas, the presence of H_2S may retard or even preclude plant development.

20. Oxidation of the sulfides to sulfates may result in a decrease in the pH of the dredged material upon drying, thereby creating severely acid soil conditions.[102,114] Vegetation growing under such acid conditions must be able to tolerate low pH and higher concentrations of aluminum, manganese, and iron. Other heavy metals,

such as zinc, copper, nickel, and cadmium, when present, may become more soluble under acid conditions.

Lead

21. Plants do not appear to be able to take up and translocate large amounts of lead from soils to upper stems and leaves.[115-117] Results of a study with ryegrass suggest that plant roots impede the transport of lead to aboveground plant parts.[115]

22. Lawrence measured the concentration of lead in several aquatic plants growing in sediments containing approximately 110 ppm of lead.[27] The lead content of the plants in this study ranged from 14 to 52 ppm. Eichornia crassipes, Alternanthera philoxeroides, and Myriophyllum spicatum contained larger amounts of lead, while Justicia americana and Zizaniopsis miliacea contained 14 and 15 ppm, respectively (Table D2). A. philoxeroides was able to remove 1.12 kg/ha of lead while the other four species each removed less than 0.5 kg/ha (Table D3). Rolfe determined the lead content of several tree seedlings grown in soil containing 600 ppm of lead, which is greater than the lead content of most dredged material.[68] The uptake and concentration of lead in the stems and leaves of the seedlings were minimal.

23. Based on the above discussion of some of the literature available on lead uptake and mobility in plants, it is suggested that the amount of lead removed from dredged material by vegetation would be insignificant.

Mercury

24. Literature concerning the mercury content of plant tissue and differential uptake of mercury by various plant species is limited, since analyses for mercury have been crude. However, new techniques and technologies are being developed and more information should be forthcoming. In a study in which organic and inorganic forms of mercury were added to a lake sediment supporting Myriophyllum spicatum, vegetative uptake of organic mercury exceeded uptake of the inorganic form.[12] In a study of mercury accumulation in a diked disposal area in the Buffalo Harbor, Perrott found that the plant life, benthos, and plankton associated with dredged material containing up to 6.4 μg/g

of mercury did not accumulate appreciable quantities of mercury.[42] Although the general capacity of aquatic plants to accumulate mercury remains controversial, some rooted plants appear able to function well in this regard.

Iron

25. Since the Earth's crust contains an average of 51,000 ppm of iron[95] and the tissue content of most plants is considerably less than 10 percent of this value, plant removal of iron from dredged material would be insignificant. It is also unlikely that the iron concentration of dredged material would ever limit plant growth, unless other constituents of the environment became limiting as affected by an iron excess.

Manganese

26. Under optimal conditions for growth, Boyd estimated the manganese uptake capability of various aquatic plants to range from 13 to 296 kg/ha.[28] Under natural conditions, this range is estimated to be from 2 to 20 kg/ha.[27,29] Based on the extremely high manganese concentrations reported for some freshwater floating plant species, it appears that these are able to remove large quantities of this element from the aquatic medium. Species of *Typha* (cattail), attached freshwater aquatic plants, are also capable of relatively high absorption of manganese. Uptake of manganese by salt marsh plants appears to be of a generally lesser magnitude than that of freshwater species. For example, Broome et al. found that *Spartina alterniflora* removed only about 0.1 kg of manganese per hectare of salt marsh (Table D3).[85]

27. These results indicate that freshwater plant species might be more useful in removing manganese from dredged material than saltwater plant species. Since the Earth's crust contains an average of 1000 ppm of manganese,[95] the vegetative uptake of this element may be of only minor importance in terms of contaminant removal from dredged material.

Aluminum

28. Aluminum, a quantitatively important constituent (81,000 ppm)[95] of the Earth's crust, is normally bound within crystalline lattices and as a hydrated oxide. In these forms, maintained at near neutral pH, it is unavailable for absorption by plants. However,

in acid soils of pH 5.0 or below, aluminum becomes solubilized and may become phytotoxic. Uptake of aluminum from dredged material by plants is quantitatively unimportant. The presence of this element in a dissolved form at relatively high concentrations need only be considered from the standpoint of phytotoxicity.

Zinc

29. Freshwater plants have been reported to contain from 22 to 960 ppm of zinc under various environmental conditions (Table D2). *Lemna* spp. and *Spirodela* spp. have been found to contain as much as 960 ppm of zinc.[59] Both *Eichornia crassipes*[27] and *Justicia americana*[28,29] have been reported to contain over 200 ppm of zinc. Boyd has calculated that *J. americana* can remove 30 kg/ha of zinc annually.[28] Other freshwater species have been reported to be able to remove 6 kg/ha or less of zinc.

30. Gosselink et al. found that *Phragmites communis* contained higher amounts of zinc than did other brackish and also saltwater plant species studied.[41] Therefore, except for *P. communis*, most brackish and saltwater plant species may not be useful in the removal of zinc from dredged material.

Copper

31. *Alternanthera philoxeroides* and *J. americana*, both freshwater plants, have been reported to contain as much as 243 and 147 ppm of copper, respectively.[27] Uptake of copper by these two plants has been estimated at approximately 15 kg/ha.[27] Brackish and saltwater plant species generally contain 11 ppm or less of copper; thus these plants are less likely to be effective in the removal of copper on an areal basis. Although small quantities of copper are essential for plant life, relatively large concentrations are notably phytotoxic. These data suggest that while certain aquatic plants appear to have some potential to remove copper from dredged material most plants will remove insignificant amounts.

Nickel

32. Nickel has not been shown to be essential for plant life, although it is found in very low concentrations in most plants.

Lawrence found the nickel content of some freshwater plants to range from 18 to 38 ppm.[27] Furthermore, Lawrence estimates that aquatic plants remove less than 0.5 kg/ha of nickel.[27] In general, it is unlikely that aquatic plants would be of any importance in regard to the removal of nickel from dredged material.

Cadmium

33. Cadmium has not been shown to be essential or toxic for plant life; however, cadmium can accumulate in animals with detrimental effects.[118] Lawrence estimates the cadmium content of aquatic plants grown in sediment containing 37 ppm cadmium (aqua regia acid digestion) to range from 4 to 19 ppm.[27] Quantities of cadmium removed by these aquatic plants were less than 0.2 kg/ha. These data, though sparse, suggest that the removal of cadmium by plants from dredged material would be insignificant.

Chromium

34. While chromium has not been demonstrated to be essential for plant life, it is required by animal life and is widely distributed in soil, water, and biological material.[113,119] Lawrence reports values ranging from 21 to 64 ppm for aquatic plant species grown in sediment containing 87 ppm chromium (aqua regia acid digestion).[27] Estimates of the removal capacity of aquatic plants indicate that less than 0.5 kg/ha of chromium could be removed. These results suggest that the removal of chromium from dredged material by plants would be relatively insignificant.

35. Heavy metals can interact with one another and with plants. Certain heavy metals, manganese, zinc, copper, nickel, and cobalt, have been reported to induce an iron deficiency in flax.[120] Increasing the iron content in flax tends to offset some of the toxic effects of these heavy metals.[121,122] Manganese and zinc have been shown to adversely affect iron metabolism in plants, but increasing the iron content of the plants offsets some of the effects of toxicity.[121,122] Lee reports that large quantities of aluminum can increase the uptake of iron in potato plants and can actually relieve some of the toxic effects of manganese.[123] These are some examples of heavy metal interactions. The

aquatic plants listed in Table D3 tend to contain relatively high amounts of iron that may offset some of the otherwise toxic effects of high contents of manganese and zinc found in some of these species.

36. The heavy metal that may be the most difficult to control within a containment area is mercury. Mercury has been shown to concentrate as it moves up the food chain.[124] Almost any mercury compound may be converted by bacteria in sediments into highly soluble methylmercury. Such conversion appears to be more rapid under anaerobic rather than aerobic conditions.[125] Anaerobic conditions would be present in a disposal site after discharge operations and therefore could result in the conversion to highly soluble methylmercury.

Oil and grease

37. The last contaminant to be discussed is the oil and grease tolerance of plants. Baker indicates that most salt marsh vegetation can recover from several successive oil spillages.[55] According to Baker, bare mud became exposed in zones dominated by *Spartina anglica* and *Puccinellia maritima* only after more than four successive spillages.[55] However, *Juncus maritimus* was severely affected by only two oilings. Cowell found *P. maritima* and *Spartina townsendii* to be most affected by oil spillage, while *Juncus gerardii* appeared to be more tolerant.[54] The impact of an oil spillage will be determined by such factors as species specific sensitivity, the stage of growth of the plant species, and the concentration and type of the spilled oil.

APPENDIX E: DEWATERING OF DREDGED MATERIAL

Introduction

1. Until recently, it was common practice to abandon a confined disposal area after filling with dredged material. The service life of a disposal area may, however, be increased by employing techniques to increase the density and thereby reduce the volume of the dredged material. By promoting the consolidation of dredged material, the bearing capacity and shear resistance of the material are also increased. Unfortunately, conventional techniques for consolidating dredged material by removal of water are often quite expensive.

2. This appendix evaluates the feasibility of using vegetation to dewater and thus consolidate dredged material. There are a number of questions that should be considered. How does water removal by vegetative transpiration compare with removal from the soil surface by evaporation? Which plants can be used for particular types of dredged material in various climates? How can a plant community be successfully established in a disposal area?

3. The combined effect of water loss from leaf surfaces (transpiration) and from soil surfaces (evaporation) is referred to as evapotranspiration. Water loss through evapotranspiration is generally much greater than loss through evaporation alone because of the increased drying surface provided by the presence of vegetation. A bibliography, compiled by Horton, lists 713 references concerning evapotranspiration of phreatophytes growing along streams.[126*] Phreatophytes are characterized by their ability to consume large volumes of water and to extend their root system to considerable depths as the water table recedes. These characteristics are those required for optimal dewatering of confined dredged material.

4. Extensive research related to the stabilization of drained

* Raised numbers refer to similarly numbered items in the References at the end of the main text.

lake and sea sediments has been undertaken in the Netherlands, where the Dutch have rigorously tested methods of vegetative dewatering with much success.[14,15] Sediments stabilized through the use of vegetation were of variable texture, ranging from coarse to very fine. Both freshwater plants and those adapted to saline conditions were propagated on sediments from freshwater and marine environments, respectively. Many of the plant species used extensively by the Dutch are native to the western United States.

Physical and Biological Dewatering Processes

Evaporative loss of water from soil surfaces

5. It has been demonstrated that surface evaporation is only effective in drying most terrestrial soils to depths of 10 to 30 cm. As the soil surface dries, capillary conductivity and thus liquid flow across the drying layer approach zero.[17] The depth of soil drying by surface evaporation is reduced by a decrease in soil particle size and increase in rate of drying.[127] Whether these relationships are also true in the case of dredged material is an unresolved question at this time.

Transpirational loss of water from soil

6. Depending upon the depth of root penetration, transpirational dewatering of soil by plants can proceed to depths considerably greater than the depth to which surface evaporation is effective. Water is absorbed from the soil at root hair-soil particle interfaces and transported through a specialized conducting system to the leaves where it is transpired to the atmosphere. Daily transpiration patterns are directly correlated with increasing temperature, decreasing relative humidity, and increasing evaporation rates. In general, the magnitude of transpirational water loss from an area is dependent upon the water content of the soil, the climate, functional leaf area, and physiological condition of the vegetation.

Extent of Soil Desiccation as Influenced by Root Development

Lateral extension

7. Vegetative dewatering is essentially restricted to regions of root occupancy; thus the extent of soil desiccation is enhanced by expansion of the root zone. In damp soils, rooted organs initially expand laterally, partially because the impetus for vertical expansion (low moisture) is absent. No general guidelines are available to use as indices of the amount of time required for maximal lateral development of a root system. Aside from both the mode and extent of plant propagule introduction, the species of plants introduced, edaphic conditions, and climatic conditions would also influence the rate and extent of lateral root growth in a dredged material disposal area.

Vertical extension

8. Soon after closure of the floral canopy, the water content of the upper soil stratum often becomes limiting. In response to this moisture stress, the root system continues to grow downward. Plant species differ in the ability of their root systems to migrate vertically; consequently, shallow-rooted species dry the soil strata near the surface, whereas deep-rooted species are needed to dry out subsurface soil strata.

Restriction of rooting depth

9. The specific rooting depths of plant species are relatively inexact because root growth is drastically affected by various environmental conditions. Root growth is commonly retarded in soils of low fertility and by toxic substances, restricted aeration, adverse temperature, high density, and mechanical impedance.[128]

10. Underground stems, such as rhizomes, tubers, and bulbs, as well as some aerial stems are able to produce adventitious roots that function identically to true roots. Salix spp., among other trees, and some herbaceous plant species such as Phragmites communis (Figure E1) can generate adventitious roots from stems buried under newly deposited sediments. Vegetative stands with this capability would be useful in

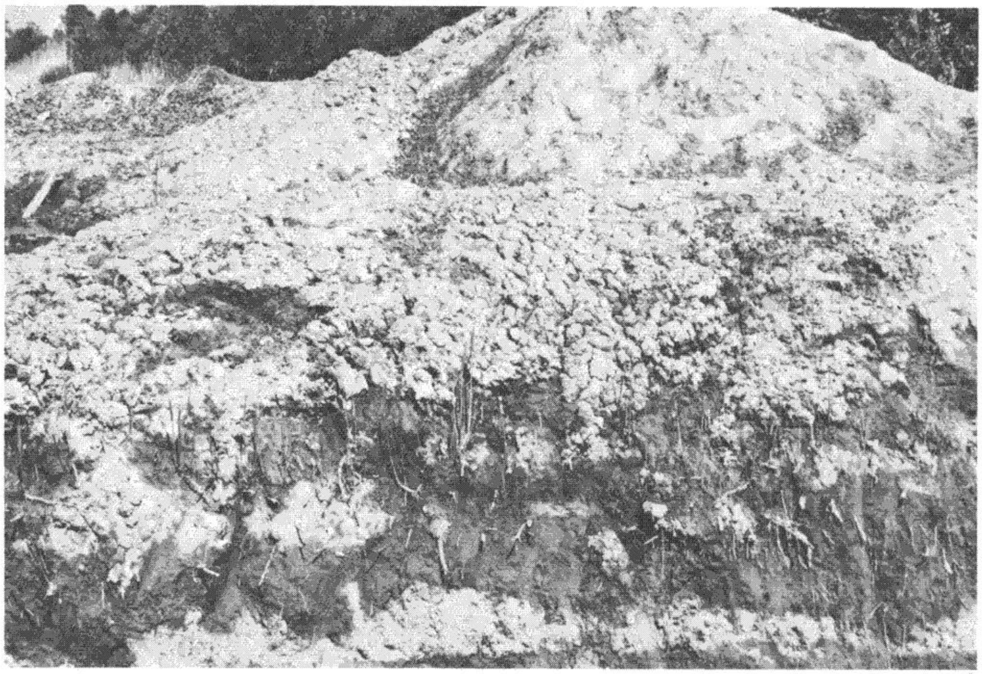

Figure E1. Regeneration ability of Phragmites communis following burial beneath 2 m of dredged material

dredged material disposal sites where the deposition of dredged material is frequent.

Habitat Specific Rooting Limitations

Wetland vegetation

11. The rooted organs of attached wetland vegetation develop in substrata that are generally much less suitable for their development than are terrestrial soils. The poor aeration of wetland sediments and the accumulation there, as well as in the overlying water, of anaerobically released organic and inorganic growth repressing substances may pose physiological problems for rooting organs.[129]

12. Colonization of dredged material wetlands for the purpose of dewatering can be done most effectively using wetland-adapted vegetation that is genetically suited for growth under such poor conditions. Lateral root growth by most wetland plant species can be expected to be quite vigorous and extensive. However, vertical root penetration by

these plants is generally less extensive, due to inherent problems involving gaseous exchange.

13. Although wetland plants are typically surface rooted,[130] *Phragmites*[63] and other plants possessing highly adapted internal gas transport systems are able to root much more deeply. Habitat-related variations in the rooting depth of *Phragmites communis* are given in Table E1, modified from Haslam.[63]

Terrestrial vegetation

14. Terrestrial vegetation is normally deeper rooted than wetland vegetation. Unfortunately, terrestrial plants generally cannot tolerate anaerobiasis; thus they cannot survive in poorly drained habitats. For this reason, terrestrial vegetation generally cannot be established on freshly dredged material. Once the surface is drained, however, terrestrial vegetation can be used to dewater deeper strata within disposal areas.

Rate of Soil Drying

Water loss within various climatic regions

15. Values of peak daily water loss for various crops in different climatic regions are shown in Table E2. These estimates of water loss assume complete crop cover and a soil moisture content at field capacity. Evapotranspirational water loss would be reduced at a lower soil moisture content[128] and with incomplete crop cover.

16. Given a sustaining soil moisture content, annual water loss per unit area of soil surface, with complete vegetative cover, is dependent upon local climatic conditions. In general, evapotranspirational water loss in tropical and semitropical regions can be expected to be greater than that in temperate regions where the growing season is reduced.

Seasonal aspects of water loss

17. An example of monthly and cumulative water loss throughout the year from vegetated and lake surfaces is given in Figure E2.[36] Peak losses occurred during the midsummer period, and losses during the

Table E1

Depth of *Phragmites communis* Rhizomes[63]

Rhizome Depth below Soil Surface, cm	Water Table Range in Relation to Soil Surface, cm	*Phragmites* Performance	Habitat
10 and below	+15 to -20	Dominant	Nutrient-rich marsh
25-80	-20 to -80	Sparse	Nutrient-rich marsh
25-60	0 to -40	Fairly dense	Nutrient-rich marsh
30-80	-10 to -90	Sparse	Nutrient-rich marsh
15-50	+2 to -2	Sparse	Nutrient-deficient marsh
20 over 150	≈+30 to -15	Dominant	Nutrient-medium marsh
10 and below	≈+60 to +20	Invading	Dike in marsh
5-15	≈+50 to +30	Sparse	Nutrient-poor lake, stony
30 and below	≈+60 to +20	Sparse	Nutrient-poor lake, sandy
20-60	Slope, no permanent water table	Fairly dense	Grassy slope
50-100 & below	≈-100 to -150	Dominant	Deep alluvial soil
5 and below	≈+50 to +15	Invading	Dike in alluvial soil
5-30	+5 to -20	Dwarf, fairly dense	Toxic salt in saltmarsh

Table E2

Daily Water Loss by Crops Within Various Climatic Regions[127]

Crop	Area*--Daily Water Loss, cm/day						
	1	2	3	4	5	6	7
Lucerne	0.43	0.55	0.63	0.73	0.88	0.76	0.45
Pasture	0.43	0.55	0.63	0.71	0.88	0.76	0.45
Grain--small	0.40	0.50	0.50	0.50	--	--	--
Beets--sugar	0.45	0.55	0.55	0.71	--	--	--
Beans--field	0.40	0.45	0.50	0.50	0.76	--	--
Corn--field	--	0.63	0.76	0.76	0.88	0.76	0.40
Potatoes	--	0.45	0.55	0.71	0.76	0.50	0.38
Peas	0.40	0.45	0.45	--	0.63	0.50	--
Tomatoes	0.40	0.45	0.45	0.50	0.76	0.50	0.38
Apples	--	0.50	0.50	0.55	0.76	0.63	--
Cherries	--	0.50	0.50	0.55	--	--	--
Peaches	--	0.50	0.50	0.55	0.76	0.63	0.35
Apricots	--	0.50	0.50	0.50	--	--	--
Tobacco	--	--	--	--	--	0.63	0.35
Vegetables	--	--	0.50	0.63	--	0.50	0.30
Strawberries	0.45	0.50	--	0.63	--	0.38	--

* Areas of the United States are as follows:

1 West coast: southern half in fog belt.
2 West coast: northern half and southern coastal interior.
3 Central valley: California and valleys east side of Cascade Mountains.
4 Intermountain: desert and high plains.
5 Mississippi: interior valleys.
6 Great Lakes
7 Atlantic and Gulf coastal zone.

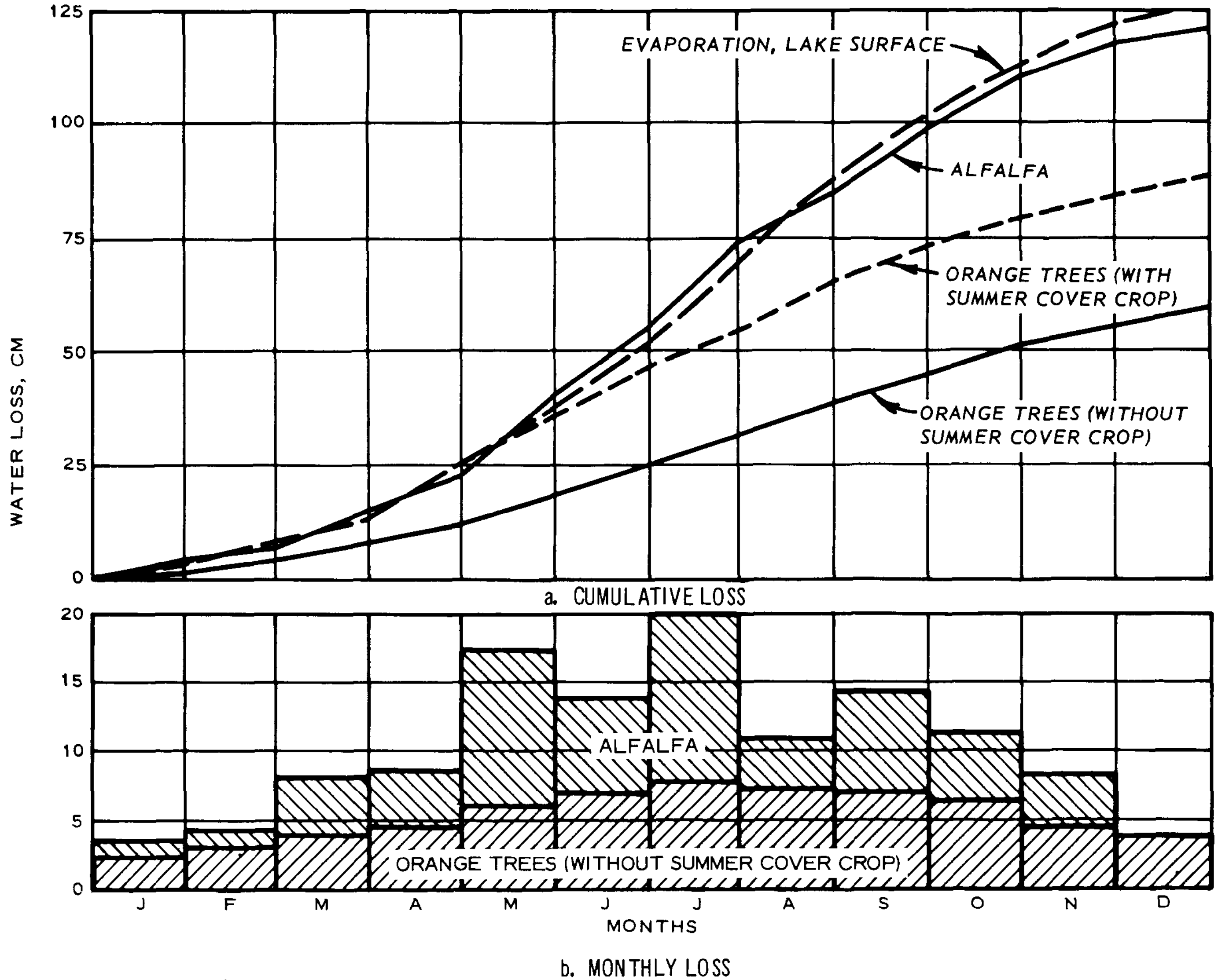

Figure E2. Water loss from vegetated and lake surfaces[36] winter were minimal. Cumulative water loss from the alfalfa community was greater than that from either of the two orange tree communities, indicative of the lesser evaporative surface of the latter. Water losses from both the lake surface and the alfalfa community were comparable in this study.[36] In other studies,[131,132] it has been demonstrated that evapotranspirational water, particularly from emergent aquatic plant communities,[20] commonly exceeds evaporative water loss from an equivalent surface of open water.

Drying rate as a
function of soil moisture content

18. As soil begins to dry, foliage and root function are affected, and at some point thereafter the drying rate decreases. The type of vegetation determines the point at which drying rate is affected, as well as the shape of the response curve. It is generally agreed that the rate of water loss diminishes as the soil dries out.[128]

19. Soil moisture depletion curves are commonly developed to integrate the drying effects of soil surface evaporation, drainage, and transpiration. In the wet condition, all processes occur and the rate of soil drying is maximal. Once the soil is drained and the surface is dried, the drying rate, particularly at the surface, drops as transpiration diminishes with decreased soil moisture content.

Degree of Soil Drying by Vegetation

Soil-water values

20. In considering the use of vegetation as a dewatering agent, information on the degree to which vegetation can dry different soil types is important. Broadfoot and Burke[133] summarize soil-water values based on U. S. Department of Agriculture (USDA) data for textural classes and other sources. Figure E3 presents values of water content obtained in field and laboratory tests on terrestrial soils of various texture, supporting a variety of vegetation from cropland to forest. Values are based on oven-dry weight of soil. Values for F max and F min refer to the highest and lowest water contents measured in field

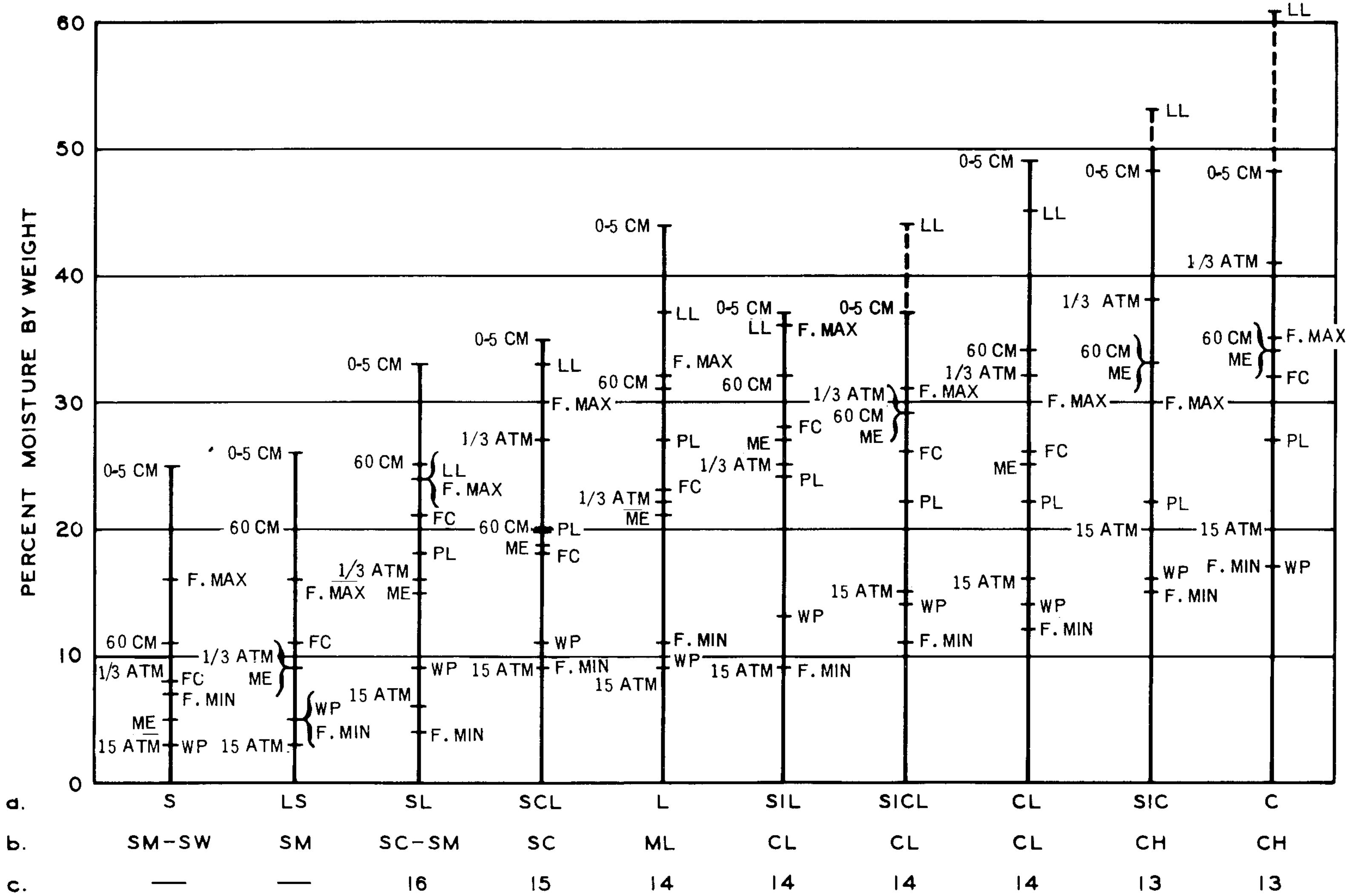

Figure E3. Soil-water values of various textural classes of surface and subsoils: (a) textural classes;[133] (b) Unified Soil Classification System;[134] and (c) shrinkage limit percent water content[135] studies.[136] WP, ME, FC, LL, and PL refer to wilting point,[17] moisture equivalent,[17] field capacity,[17] liquid limit,[137] and plastic limit,[137] respectively. Based on these limits, USDA textural classes were converted into the Unified Soil Classification System.[134]

Plastic limit

21. Dredged material slurry commonly contains between 10 and 20 percent solids by weight.[16] This corresponds to a water content of between 400 and 900 percent of the oven-dry material. After settling, the water content of the dredged material slurry can be expected to reduce to a range of 60 to 140 percent, assuming water contents of 30 to 50 percent at saturation (Figure E3) and incorporating factors for fluff of bulking during dredging.[16] In general, such water contents exceed the LL of soils as shown in Figure E3; thus, these soils would be too soft to support the weight of a man. By vegetative drying, soil moisture can be further reduced to the water contents expressed in Figure E3 at 15 atm, the WP. These values range from 5 percent for sand and plastic fines (SC-SM) to approximately 20 percent for clay (CH). Soils having water content in this range could easily support the weight of a man.

Shrinkage limit

22. The shrinkage limit of a soil is expressed as the water content at which there is no further decrease in volume associated with further evaporation of pore water. Following vegetative drying to minimum water content (WP), shrinkage is complete for coarse-grained soils with plastic fines and for fine-grained soils with low plasticity. For more plastic (CH) soils, shrinkage would be approximately 90 percent complete after vegetative drying to the WP.

Selection of Vegetation for Dewatering Dredged Material

23. In selecting vegetation for the purpose of dewatering dredged material, consideration must be given to the local climate, the chemical and physical nature of the material to be dewatered, the desired rooting depth, the time allotted for growth, and the availability of selected

propagules. In the United States, the selection of potentially useful plant species for dewatering dredged material is complicated by the diversity of climate and substrata types. Any listing of species for use in confined dredged material areas within a specific geographical region can only be developed after a considerable amount of site specific research. However, Table B1 gives general guidance for the value of several species for dewatering under varying conditions, and should serve as a good basis for further development.

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Lee, Charles R

Feasibility of the functional use of vegetation to filter, dewater, and remove contaminants from dredged material, by Charles R. Lee, Ronald E. Hoeppel, Patrick G. Hunt, [and] Charles A. Carlson. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1976.

1 v. (various pagings) illus. 27 cm. (U. S. Waterways Experiment Station. Technical report D-76-4)

Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under DMRP Work Unit 2C02.

Includes bibliography.

1. Contaminants. 2. Dewatering. 3. Dredged material. 4. Filtration. 5. Slurries. 6. Vegetation. I. Carlson, Charles A., joint author. II. Hoeppel, Ronald E., joint author. III. Hunt, Patrick G., joint author. IV. U. S. Army. Corps of Engineers. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Technical report D-76-4)

TA7.W34 no.D-76-4