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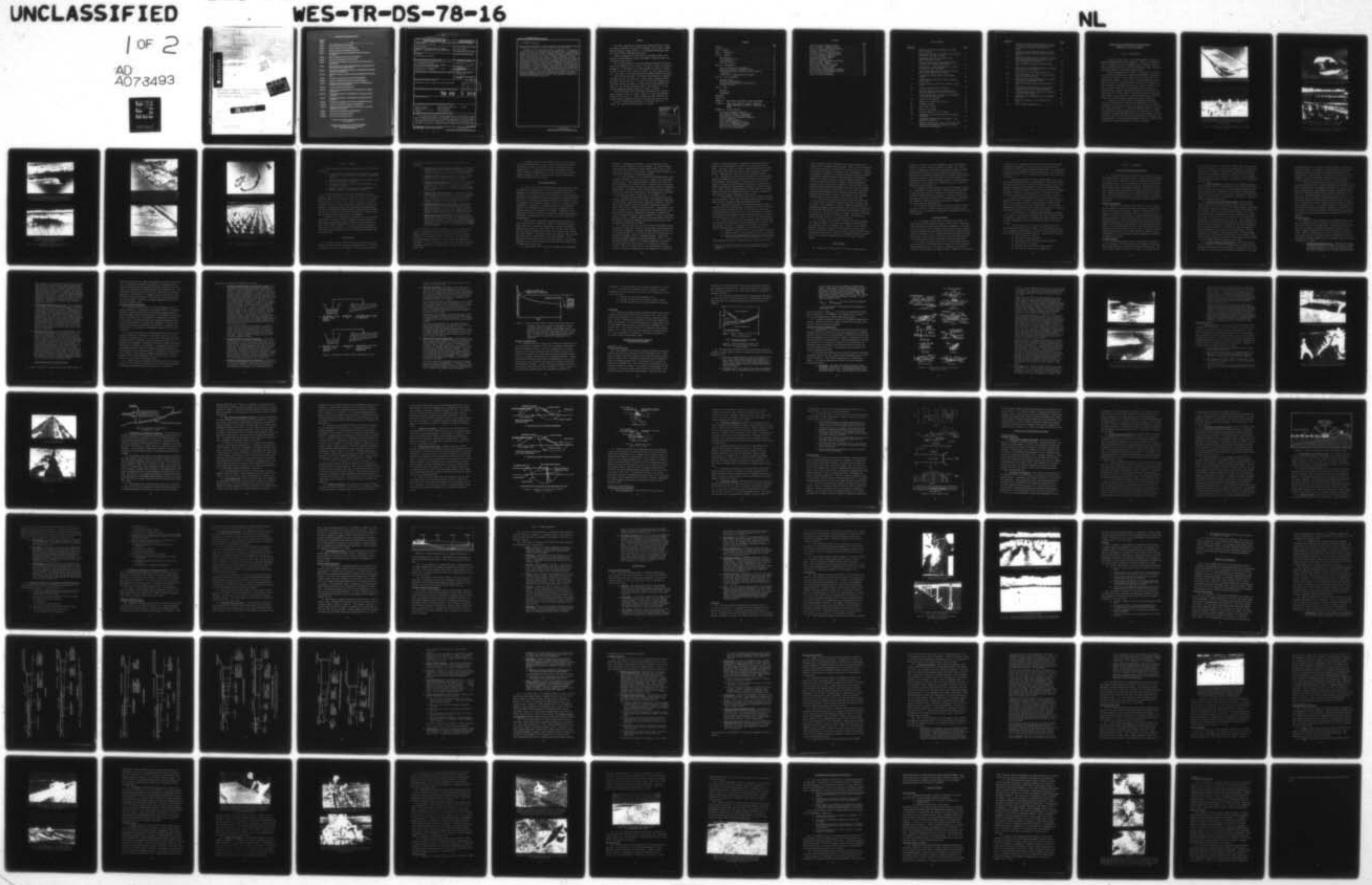

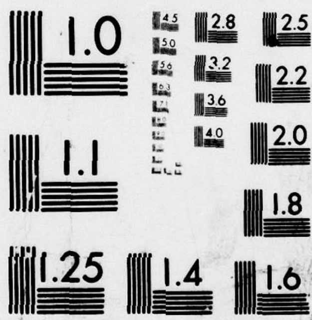

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WETLAND HABITAT DEVELOPMENT WITH DREDGED MATERIAL: ENGINEERING AND PLANT PROPAGATION

December 1978
Final Report

Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

THE DMRP SYNTHESIS REPORT SERIES

Technical Report No.	Title
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DS-78-17	Upland Habitat Development with Dredged Material: Engineering and Plant Propagation
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Marsh habitat development using dredged material as a substrate was shown by the Dredged Material Research Program (DMRP) to often be a feasible alternative to traditional dredged material disposal operations. This report synthesizes pertinent literature and research of the DMRP including six major marsh development field sites: Windmill Point in the James River, Virginia; Buttermilk Sound on the coast of Georgia; Bolivar Peninsula in Galveston Bay, Texas; Con't

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Miller Sands, Columbia River, Oregon; Drake Wilson Island in Apalachicola Bay, Florida; and Salt Pond No. 3, South San Francisco Bay, California.

Guidelines for developing marsh habitat are presented: (a) planning the project in relation to the proposed site and project goals; (b) engineering construction of the site including dredging operations; (c) propagation, maintenance, and monitoring of the site as habitat, including potential problems that may be encountered; and (d) costs. Emphasis is placed on two major areas: engineering and plant propagation. Engineering aspects and design of potential sites are discussed and include protective and retention structures, substrate and foundation characteristics, dredging operations, and elevation and drainage requirements. Phases of plant propagation are detailed in the text and tables: selecting plant species for the site, collecting and storing plant materials, selecting a propagule type, planting the site, maintaining and monitoring the site, pilot studies, costing the work, and allowing natural colonization. A synopsis of 28 plant species discussing their characteristics, value, and potential use on dredged material is included as an appendix. Tables of 115 selected plant species showing best propagules; occurrence by region and whether now occurring on dredged material; growth requirements; propagule handling methods; soil, salinity, and inundation tolerances; and other pertinent information are given.

PREFACE

This report synthesizes literature and research pertinent to marsh development conducted by the Habitat Development Project (HDP), Dredged Material Research Program (DMRP), U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi.

Research synthesized in this report was performed by WES, other Federal and state agencies, private individuals, consulting firms, and educational institutions.

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Review of various phases of the report was provided by Dr. Raymond Montgomery, EL; Mr. John Lunz, EL; Dr. Gary Tucker, Arkansas Polytech University, Russellville; Dr. B. R. Wells, University of Arkansas Rice Experiment Station, Stuttgart; Dr. Edgar Garbisch, Environmental Concern, Inc., St. Michaels, Maryland; and Mr. Paul Knutson, U. S. Army Coastal Engineering Research Center, Ft. Belvoir, Virginia.

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Director of WES during preparation of the report was COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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WETLAND HABITAT DEVELOPMENT WITH DREDGED MATERIAL: ENGINEERING AND PLANT PROPAGATION

PART I: INTRODUCTION

1. Marsh development refers to the establishment of relatively permanent nonwoody wetland plant communities. The use of dredged material as a substrate for marsh development offers a disposal technique that is, in many situations, a feasible alternative to more conventional open-water, wetland, or nonwetland disposal options.

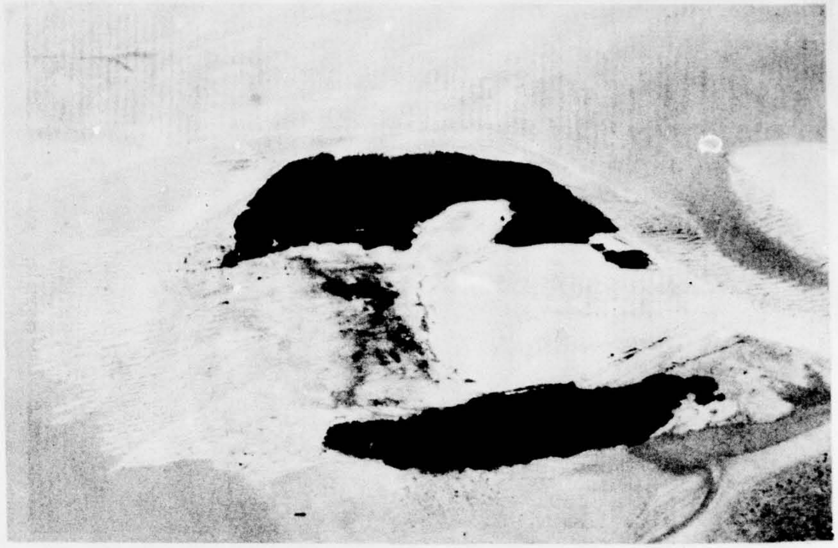
2. Marsh development was the subject of an intensive research effort within the Dredged Material Research Program (DMRP), and reliable techniques were evolved to plan, design, cost, construct, plant, and maintain these systems. A wide variety of studies conducted under the DMRP are pertinent to marsh development and are listed in Appendix A. The cornerstone of this DMRP effort was the series of studies at field sites located at Windmill Point, James River, Virginia (Figure 1); Buttermilk Sound, Atlantic Intracoastal Waterway, Georgia (Figure 2); Apalachicola Bay, Florida (Figure 3); Bolivar Peninsula, Galveston Bay, Texas (Figure 4); Salt Pond No. 3, South San Francisco Bay, California (Figure 5); and Miller Sands, Columbia River, Oregon (Figure 6).

3. Experience and data obtained from DMRP marsh development studies and from pertinent literature are synthesized in this report. Instructions and advice are provided for planning, building, and managing a marsh development site. Other DMRP synthesis reports of particular significance to marsh development are "An Introduction to Habitat Development on Dredged Material" (Smith 1978), which presents a routine for habitat selection, and "Upland and Wetland Habitat Development with Dredged Material: Ecological Considerations" (Lunz et al. 1978a), which discusses the theoretical concepts of habitat development.

a. An aerial view of the 8-ha freshwater marsh developed on fine-textured dredged material confined by a sand dike

b. Within 6 months of dredged material placement a lush growth of wetland plants had established by natural colonization

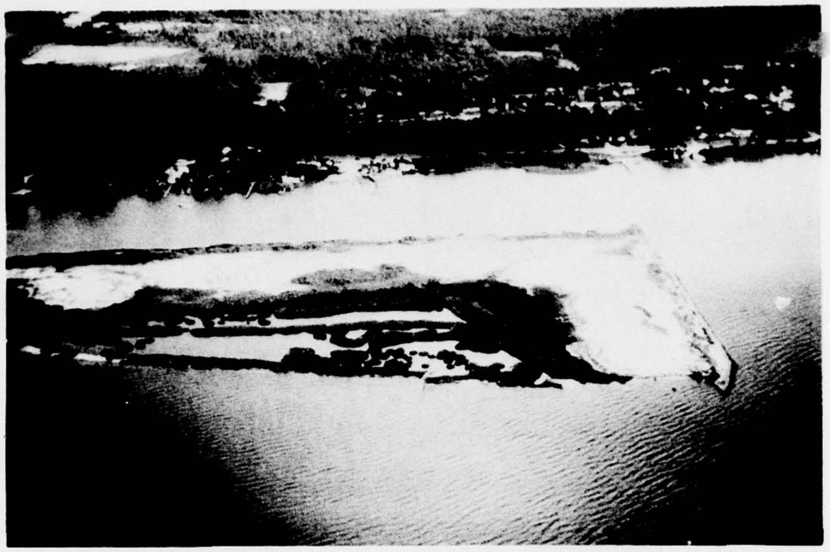
Figure 1. Windmill Point marsh development site, James River, Virginia



a. The site was formed by grading this sandy dredged material island to achieve a 2-ha intertidal area

b. The intertidal area was planted to test seeds and sprigs of seven plant species at five fertilizer rates and three intertidal elevations

Figure 2. Buttermilk Sound marsh development site, Atlantic Intracoastal Waterway, Georgia



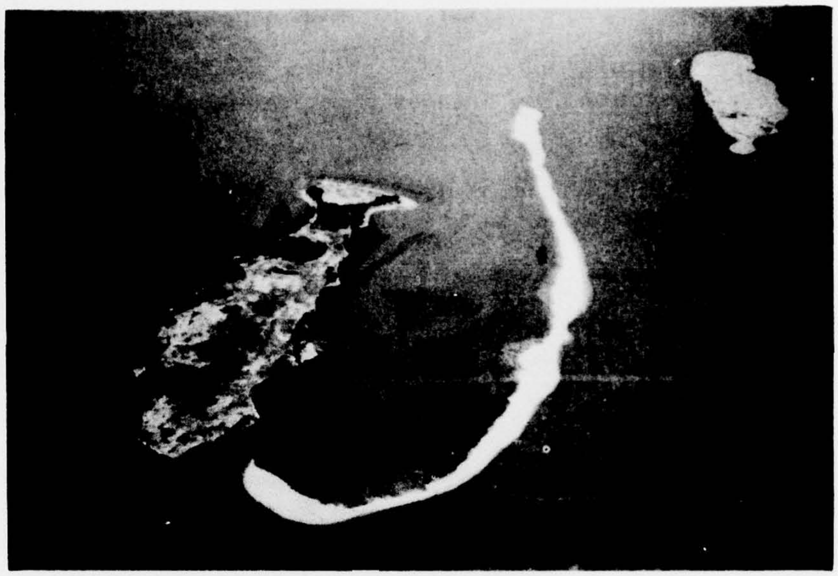
a. A salt marsh was established on poorly consolidated fine-textured dredged material confined behind an earthen dike on this dredged material island

b. Vigorous growth was obtained from sprigged smooth cordgrass and salt-meadow cordgrass

Figure 3. Apalachicola Bay marsh development site, Apalachicola Bay, Florida

Figure 4. Bolivar Peninsula marsh and upland habitat development site, Galveston Bay, Texas. A 4-ha intertidal salt marsh was established on sandy dredged material near Galveston by seeding and sprigging smooth cordgrass and saltmeadow cordgrass. A sandbag dike was used to protect the site from wave energies, and a fence erected to exclude cattle and goats

Figure 5. Salt pond No. 3 marsh development site, South San Francisco Bay, California. Clay dredged material was placed in an abandoned salt pond and allowed to consolidate. The retaining dike was breached to allow tidal flow and the site experimentally planted with Pacific cordgrass



a. A 4-ha freshwater marsh was established in the cove between two sandy dredged material deposits

b. After one growing season, a vigorous stand of slough sedge and tufted hairgrass had become established from transplants

Figure 6. Miller Sands marsh and upland habitat development site, Columbia River, Oregon

PART II: PLANNING

4. Marsh development on dredged material may be one or more of the following:

- a. A planned method of dredged material disposal for a dredging project, as an alternative to open-water or nonwetland disposal.
- b. A means for mitigation of impacts from a concurrent or past form of dredged material disposal.
- c. A method to reclaim or develop an existing disposal site to increase its value.
- d. A method to restore a marsh that has been damaged or to protect a marsh or shoreline that is eroding.

5. Situations and locations for marsh development are highly variable. Marsh projects may be a fringe along a canal or cover several square kilometres in a river delta; they may be high or low in elevation; exposed to extremes of tides, floods, and winds, or protected; saltwater, fresh, or brackish; homogeneous or diverse in species composition. A project may involve only intertidal habitat development but can be associated with upland, island, or aquatic habitat development as well. Project size will vary, depending on the amount of fill, size of available site, and periodicity of dredging.

6. Because of this variability, the planner will need to examine each project on a specific basis so guidance on project planning in this report is necessarily general. Separate reports have been prepared on DMRP marsh development sites and may be useful as examples (Allen et al. 1978, Clairain et al. 1978, Cole 1978, Kruczynski et al. 1978, Lunz et al. 1978b, Morris et al. 1978, Palermo and Zeigler 1977, and Vincent 1978).

Site Selection

7. The site for marsh development may be selected for its suitability and potential after eliminating alternate sites, or the choice of sites may be limited or nonexistent. If more than one potential

site exists, the following criteria should be considered for site selection:

a. Availability for disposal and/or development. Questions of ownership and disposal agreements through lease, easement, purchase and removal of fill, land use understandings, or scheduling arrangements must be addressed and resolved.

b. Capacity to meet disposal needs. The area must be large enough to hold the volume of material to be dredged, whether one-time or repeated disposal is planned.

c. Proximity to dredging project. This relates to the method of dredging and capability of the dredge. Most habitat development sites will be constructed with hydraulic pipeline dredges, which have limitations of distance and height to which material can be pumped without the expense of a booster.

d. Physical and engineering features. Information for preliminary design and assessment of the needs and availability of materials and equipment is needed for site selection. Detailed tests such as analyses of foundation borings are expensive and time-consuming, so they are generally performed only at the selected site.

e. Environmental and social acceptability. Acceptability includes judgment on such factors as alteration of or impacts on existing habitat, relative value of habitats under consideration, protection of wetlands or other desirable vegetation, potential for disturbances in water quality or flow, and human perception of the project.

f. Tidal and current considerations. Erosion and scour of habitat areas caused by tidal and wave energies are important considerations for determining the longevity and stability of containment structures and habitat development. Interruption of current patterns and changes in the hydraulic regime likely to result from dredged material placement should be examined.

8. The primary criterion is feasibility of marsh development at the site. Feasibility is determined from the above factors, the severity of problems likely to be encountered, and level of effort required for a successful project. A project will be infeasible if either engineering, biological, or social aspects are unsuitable or untreatable. If this is the case, either another site must be selected or another alternative for dredged material disposal must be found (Smith 1978).

9. Guidance provided in SCS Engineers (1977) on site selection for inland dredged material disposal includes an extensive checklist that would be useful on any project. The site selection process is illustrated in U. S. Army Engineer District, San Francisco (1974). Further sources of information on site selection are Coastal Zone Resources Corporation (1976), Garbisch (1977), Johnson and McGuinness (1975), and Kadlec and Wentz (1974).

Site Characterization

10. After a site for marsh development has been designated, field and laboratory investigations of the site and related areas should be initiated to plan disposal and/or habitat development operations. If the site is an old disposal area to be reclaimed, it and the surrounding area should be described physically and biologically to determine necessary action. If dredging and disposal operations are involved, it will be necessary to add information related to the site's capacity, need for and design of a protective or retention structure, and construction details. This information should be collected in conjunction with characterization of the sediments to be dredged. Coordination among individuals involved in planning the project will improve data gathering efficiency by eliminating overlap in activities such as sampling and map preparation.

11. With an aerial photograph, topographic map, or diagram as a base, record the site's location in relation to the dredging project, other aquatic areas, wetlands, upland areas, and obvious topographic features such as hills or a river bluff. Note cultural points such as areas for housing, transportation, industry, agriculture, water treatment, and recreation. Mark access routes, both land and water, and rate them in relation to their ability to transport equipment. Use the same scale for all features to show their relationship. Aerial reconnaissance is a good way to become oriented and may reveal features that are hidden from a ground view.

12. Record details of the site such as dimensions, configuration,

bathymetry, topography, and elevation. Include mention of dikes, mounds, or other evidence of previous disposal. Note areas of debris accumulation and indications of nearby human activity such as a boat dock, cabin, foot trail, or livestock. See Mosby (1969) and Maire et al. [1976?] for techniques on reconnaissance mapping.

13. If the substrate is to be covered with dredged material, give a general evaluation of soils on the site: texture, color, and organic matter content. If the substrate already in place is to be used for marsh development, soil analysis should be conducted since soil properties influence the choice of species and potential success of vegetation establishment. Soil analyses should include particle size, available nutrients, pH, salinity, organic matter, and contaminants, if suspected to be present (heavy metals, pesticides, oil and grease, etc.).

14. Existing plant and animal species at the site should be described, especially occurrence of wetlands. Map vegetation composition and distribution, either from visual estimation or sampling. DeVos and Mosby (1969) described levels and methods of mapping and vegetation analysis that will be suited to site description. A good general reference is Chapman (1976). Sampling methods are not standardized but must be tailored to the type of vegetation, areal extent of habitat, and level of information required. Note the specific location of any plants protected by law. A botanist familiar with the area should be consulted for species verification; regional field guides such as Pierce (1977) and Silberhorn (1976) will be helpful.

15. Current wildlife use of the site should be determined through observation of sign such as tracks or browse marks, actual observations, or some form of sampling. A wildlife biologist familiar with the area can estimate wildlife use of the site and should be consulted about the presence of threatened, rare, or endangered species. Contact the appropriate Regional Endangered Species Coordinator of the U. S. Fish and Wildlife Service (Table 1) for updated information on Federally protected species and their habitats. See Coastal Zone Resources Division (1978) for a partial list of state publications on protected species, or contact the appropriate state's department of wildlife and

fisheries or natural resources. Determine the potential presence of species such as Canada geese* that may feed on newly planted marsh plants. See Murie (1954) for a guide to animal signs and Giles (1969) and the 1979 fourth edition for various field techniques on wildlife surveys. Techniques will vary with the type of wildlife present.

16. Invertebrates on the water bottom that may be covered during habitat development activities should be described by species composition, abundance, and distribution. References such as Frey et al. (1973), who sampled salt marsh benthos and burrows, Little and Quick (1976), who described a reconnaissance technique for oysters, and Wolf et al. (1975), who described sampling for fiddler crabs in salt marsh, should be consulted for sampling techniques. A general reference for field surveys of aquatic organisms is Weber (1973).

17. Characteristics of the water that will be flooding the marsh must be described. Record tidal fluctuation means, minima, and maxima; water salinity; freshwater flows; and drainage patterns.

18. Description of the site for engineering purposes includes laboratory and field investigations of substrate conditions in the area of the new marsh and under the line of any retaining or protecting structure that may be required. It also includes analysis of stability and strength of any existing structures and measurement of the stress those structures will receive. Refer to Part III for further details.

19. *Related areas to be described* include uplands associated with the proposed marsh development, existing wetlands in the vicinity, and the waterway or harbor to be dredged or other source of sediments. Adjacent habitats should be included in the site description to:

- a. Identify a potential source of plant and animal colonizers.
- b. Relate the site to other habitats with which it interacts.
- c. Determine any adverse impacts that can be avoided or situations that might influence acceptability of the project.

These areas may ordinarily be sampled with less detail than the site

* Common and scientific names of plants and animals are given in Appendix B.

itself, with plant species composition and relative distribution or perhaps only the dominant species recorded. Areas of wetland vegetation up to 5 km away should be considered, since they may serve as a source of propagules for natural or intentional plant establishment. A general description of wildlife use of adjacent and nearby habitats will identify potential colonizing species, both desirable and pestiferous. Examine sites from the viewpoint of animal movement potential; e.g., corridors of vegetation or water, distance from similar habitats, migration routes, and barriers to movement. Areas that might be adversely impacted by habitat development activities (such as a wetland that will be crossed by a disposal pipe or the nest site of an endangered species that should not be disturbed by operations during the breeding season) should be located. Residential or other developed areas and their locations relative to the site should be noted.

20. Data on water energy should be part of the site description if the site might be affected by wind and ship waves, flooding, tides, or currents. This information is used to estimate wave runup, dike freeboard requirements, erosion potential, and construction difficulties. The key tidal relationships in establishing and maintaining habitat are the elevation of the water relative to the land, the range of the tidal fluctuation, and the force of the tidal change. Tidal ranges are readily available from the U. S. Geological Survey.

21. The source of the sediments should be surveyed to determine the volume of sediments to be moved, and sampled to provide material for engineering and soil laboratory tests. See Part III for details. Samples to determine suitability of the sediments for plant growth should be analyzed for particle size, sulfates, salinity, organic matter, and suspected contaminants. Samples for contaminant analysis should be taken in an oxygen-free atmosphere and frozen to prevent chemical changes.

Goal Definition

22. Although the overall objective of marsh development may be

understood, a concept of the most appropriate type and configuration of marsh to be built in any one situation is needed. This concept should be formulated by consideration of upland and aquatic habitats associated with the marsh, as well as human-related influences. To better define his habitat development goal, the planner should consider ecological principles, local and regional needs and opportunities, target species needs, available funding, and site- or project-specific constraints. Refer to Hunt et al. (1978) and Lunz et al. (1978a) for suggestions on goal definition.

23. Examples of goals associated with marsh development projects are: stabilization of newly placed or eroding substrate, improvement of water quality, provision of refuges for fish and wildlife, and increase in biomass production and export. To meet the project goal, the planner will need to be aware of the characteristics, attributes, and tolerances of marsh plant species that may be propagated in an area, and select the appropriate ones.

24. As project planning advances, it may be necessary to modify the goal to allow it to remain compatible with the project and site characteristics. Flexibility in this matter is important to the success of the project.

Potential Problems

25. The planner should be aware of regulations, problems, or delays that may surface during some phase of the project. Many potential problems can be averted with additional coordination or preventative action such as public meetings, discussions with special interest groups, or meetings with local officials and state and Federal agencies. Reports on productive uses of dredged material besides habitat development provide a good review of constraints the planner might encounter (Gushue and Kreutziger 1977, SCS Engineers 1977, and Skjei 1976).

26. A number of Federal laws such as the 1969 National Environmental Policy Act, 1972 Federal Water Pollution Control Act Amendments, and 1973 Endangered Species Act apply to dredging and disposal and therefore to most habitat development projects. Summaries of these laws

are found in U. S. Department of the Interior (1976) and various Corps of Engineers regulations. State and local laws may include zoning regulations, lists of protected plant and animal species, or restrictions on collection or propagation of certain plant species. Critical Habitat designation by the U. S. Fish and Wildlife Service may affect activities at the site.

27. Obtaining permission to deposit dredged material and to use access routes may be difficult or time-consuming. Local needs, desires, land uses, and conflicts of interest with special groups or local citizens may exclude habitat development as a means of dredged material disposal. Location of and ease of access to a marsh site will determine the amount of pressure or stress put on the site by people, and may have to be controlled in some locations or at some times of the year.

28. Ownership and/or responsibility for the condition of the developed marsh must be determined. If ownership is fixed, some flexibility exists in goal definition. Disposal areas are often leased, however, or turned back to the owner after filling. Only short-term development or that specified by the owner may be possible. In addition, state laws on ownership of intertidal lands are variable.

29. The site may have to accommodate several disposal operations over a period of time; habitat development will then be either cellular or sequential. Additionally, the dredging and disposal operation itself is often unpredictable, so that project plans may have to be altered rapidly.

30. Lack of authorization for habitat development within the overall project may mean a lack of funds. If a funding base exists, it may be inadequate, unpredictable, or restricted in some fashion, which will restrict habitat development potential. Consider these questions:

- a How much money is available?
- b. When will it become available?
- c. Over what period of time is the money available?
- d. How certain is the funding?
- e. Are there items for which it cannot be used?
- f. Are there time limits on its expenditure?

PART III: ENGINEERING

Field and Laboratory Investigations

31. Field investigations and laboratory tests required for sediment characterization and substrate design in marsh habitat development are similar to those required for design of conventional dredged material disposal areas. The term "substrate" here refers to the dredged material upon which a marsh will be developed. The elements of substrate design include configuration, elevation, protection, and retention. Required field investigations and laboratory tests as they pertain to habitat development in salt or freshwater sites are outlined below. More detailed descriptions of certain procedures are contained in Palermo et al. (1978), which is considered a necessary companion to this report.

Channel investigations

32. The area to be dredged or from which fill will be brought must be surveyed to determine the volume of material to be made available for marsh habitat development. Samples of the material to be dredged are required for laboratory tests used in design of the substrate. The level of effort required for channel sediment sampling for habitat development is highly project-specific. In the case of routine maintenance work, data from prior sampling and experience with similar material may be available and the scope of field investigations may be reduced. For larger maintenance projects or new work projects, more extensive field investigations will be required. Procedures for determining sample type and location, sample quantities required, sample preservation, and for using sediment sampling equipment are described in Palermo et al. (1978).

Site investigations

33. Field investigations should be conducted at the potential habitat development site to determine bottom topography, evaluate the water energy conditions, and characterize the bottom materials. The scope of these should be tailored to the amount of existing data and

the stage of the project. In the site selection phase, adequate information can frequently be obtained from existing data, or limited field sampling may be required. From these data, alternative sites may be compared, and a preliminary design and costing of the most promising sites may be completed and used for site selection. A more thorough engineering data collection effort at the selected site is required for detailed design.

34. Bottom topography. Accurate (±3.0 cm) soundings should be made throughout the site. These data will allow construction of bathymetric plan maps used to assist in design of the substrate and retention structures, and in computation of the potential storage capacity for various configurations of the substrate. Knowledge of bottom topography is essential, even in the feasibility study stage, to allow the selection of an appropriate site.

35. Evaluation of the water energy regime. Historical data should be gathered on wind and ship waves, water surface elevation (surge height, flood stage), and river or estuary currents. These data are required to estimate wave runup, dike freeboard requirements, erosion potential, and construction difficulties (Eckert et al. 1978). Historical data may be supplemented by direct measurement of currents, wind fetches, and normal water level fluctuations and by observation and sampling of existing shorelines at the site. Much information regarding tides and currents may be available from records developed for nearsite locations and should be supplemented with onsite measurements. Stable shorelines adjacent to or near the site should be sampled for later determination of grain size of the shore material. Existing slopes of stable shorelines should also be noted. Detailed guidance on techniques for measurement and observations used in characterizing the water energy regime can be found in the Shoreline Protection Manual (U. S. Army Coastal Engineering Research Center 1977).

36. Substrate foundation investigations. These investigations must be performed at the habitat development site to define substrate foundation conditions and to obtain samples for laboratory tests. Data are needed to estimate potential foundation settlement due to placement

of the substrate and, in the case of confined disposal, to design the retention structure. Grab samples of bottom materials at potential development sites should be taken for feasibility study purposes in a similar manner to that described in Palermo et al. (1978) for channel sediments. This will allow general classification of the bottom surface materials and will aid in the selection of boring locations.

37. Substrate foundation borings should be made from boats or barges using conventional soil sampling techniques and equipment (Office, Chief of Engineers 1972, and Hammer and Blackburn 1977). These operations are expensive and time-consuming; therefore, foundation boring programs are generally conducted only for detailed evaluation of a specific site. Boring requirements are dependent upon the size of the project and upon the foundation conditions existing at the site. It is particularly important to define depth, thickness, extent, and composition of foundation strata and to obtain undisturbed samples of compressible foundation soils. If the channel sediments to be dredged are to be confined, the substrate foundation investigation must provide data for design of the retention structure. This will require that foundation borings be made along the approximate alignment of the retention structure.

Laboratory testing

38. Laboratory tests to characterize the dredged material, determine the placement of the marsh substrate, and design retention and protective structures are outlined below. Detailed soil testing procedures for the design of retention and protective structures can be found in Hammer and Blackburn (1977) and Office, Chief of Engineers (1970). Sediment characterization tests and sedimentation tests used for substrate design are identical with those developed for design of conventional land-based dredged material containment areas and discussed in Palermo et al. (1978).

a. Sediment characterization tests. Sediment characterization tests are needed to determine the need for substrate retention/protection and to design the substrate. Samples that are mixtures of coarse- and fine-grained material must be separated prior to characterization testing.

Tests required on fine-grained sediments include natural water content, Atterberg limits, organic content, and specific gravity. The coarse-grained sediments require only grain-size analysis. Results of these tests can be used to classify the sediments according to the Unified Soil Classification System (U. S. Army Engineer Waterways Experiment Station 1960). In addition, near-bottom water samples from the area to be dredged and from the habitat development site should be tested for salinity to determine if the sedimentation environment will be salt or freshwater. Detailed test procedures are presented in Palermo et al. (1978).

b. Sedimentation and consolidation tests. If the sediments to be dredged contain fine-grained material, a retention structure may be required to prevent material loss and excessive turbidity during placement. Sedimentation and consolidation tests are required to provide information on the behavior of fine-grained sediments placed within confined conditions. These tests will provide data for designing the containment area to meet effluent suspended solids criteria and to provide adequate storage capacity for the dredged material composing the marsh substrate. Detailed descriptions of test procedures and equipment for sedimentation and consolidation tests are found in Palermo et al. (1978). If the substrate is to be developed using coarse-grained material, these tests do not need to be performed.

c. Foundation soils tests. The scope and magnitude of the laboratory testing program for foundation soils will depend on the requirements for confinement and the complexity of the foundation conditions. The number and types of laboratory tests to be performed in connection with the design of the substrate and retention structure, if any, should be determined only after a careful study of foundation conditions as indicated by borings. If dikes are being considered for the retention structure, the proposed diking material should also be tested. Tables 2 and 3 present the various tests that may be included in a laboratory testing program for fine-grained and coarse-grained soils, respectively. Not all tests described in the tables are required for a given project. More detailed information regarding laboratory testing for foundation soils is contained in Hammer and Blackburn (1977) and Office, Chief of Engineers (1970).

Engineering Aspects of Substrate Design

39. Design of substrate for marsh habitat development consists of

defining elevation, slope, shape and orientation, and size (area and volume). The design must provide for placement of the dredged material within the desired limits and required elevations, allowing for settlement due to consolidation of dredged material and foundation soils. Adequate surface area or detention time must be provided for fine-grained sediments to allow settling of suspended solids in order to meet effluent criteria during construction. Various aspects of substrate design are discussed below. Procedures are equally applicable to both saltwater and freshwater sites.

Elevation control requirements

40. The most critical aspect of a marsh development project is usually attainment of a precisely defined stable elevation. Unconfined substrates, normally developed with coarse-grained dredged material, will not undergo significant settlement due to self-weight consolidation. However, settlements due to consolidation of compressible foundation soils may occur. Confined substrates are normally developed with fine-grained dredged material, and significant settlements of confined substrates may occur due to self-weight consolidation. In addition, settlements due to consolidation of compressible foundation soils must be considered.

41. One-time construction of confined substrates presents the most critical requirement of prediction of settlements, since the initial placement of dredged material must be such that a final elevation within acceptable limits is achieved. Since the substrate surface cannot be raised by later placement of additional material, the design must include predictions of settlement to be expected. In incremental construction, the substrate surface elevation is raised by supplemental placement of dredged material and an exact prediction of settlement for initial layers is not required. Field experience gained by observation of settlement behavior of the initial dredged material layer may be used to aid in prediction of settlement of subsequent layers.

42. Elevation control requirements are presented in the following discussion. The procedures generally resemble those required for design of land-based dredged material containment areas. More detailed

information is contained in Palermo et al. (1978).

a. Correlate sediment volumes with substrate volumes. The determination of substrate elevation and configuration is governed by either of two constraints, illustrated in Figure 7. Under the conditions of the first constraint, the project requires placement of a given in situ channel sediment volume, and the required volume occupied by the substrate must be determined. Under the conditions of the second constraint, the project requires that a substrate be constructed within given limits. The volume of in situ channel sediment required to construct the substrate must be determined. Estimates of substrate and sediment volumes can be made using the techniques and examples outlined in Palermo et al. (1978). In unconfined situations, little, if any, fine-grained sediment present will be retained in the substrate. Therefore, the total substrate volume will be equal to the volume of coarse-grained sediment. If the substrate limits are constrained, the total volume occupied by the substrate may be directly computed using the bottom topography data collected by field surveys. This assumes dredged material was placed to the mean high water (MHW) elevation (one-time construction) or assumes incremental elevation (incremental construction).

   If the substrate limits are constrained, a correlation between the in situ fine-grained sediment volumes and volumes occupied by the substrate must first be determined. Only the fine-grained sediment will undergo a significant change in volume when placed in the containment area. The coarse-grained sediment may be assumed to undergo negligible change.

b. Determine surface area and configuration. If the substrate limits are constrained, surface area may be determined directly. If not, an initial surface area may be determined by examining total volume occupied by the substrate and the bottom topographic survey data at the proposed site. The optimum substrate limits may be determined based on existing depths and the total volume requirement. Maximum use of existing topographic features should be made to reduce retention and protection requirements as much as possible. An initial assumption of material placement to the MHW elevation should be used in determining approximate surface area requirements.

c. Determine average substrate lift thickness. Examination of the bottom topographic data within the substrate limits will allow determination of an average substrate lift thickness (the average thickness of dredged material at the completion of dredging). This figure may also be

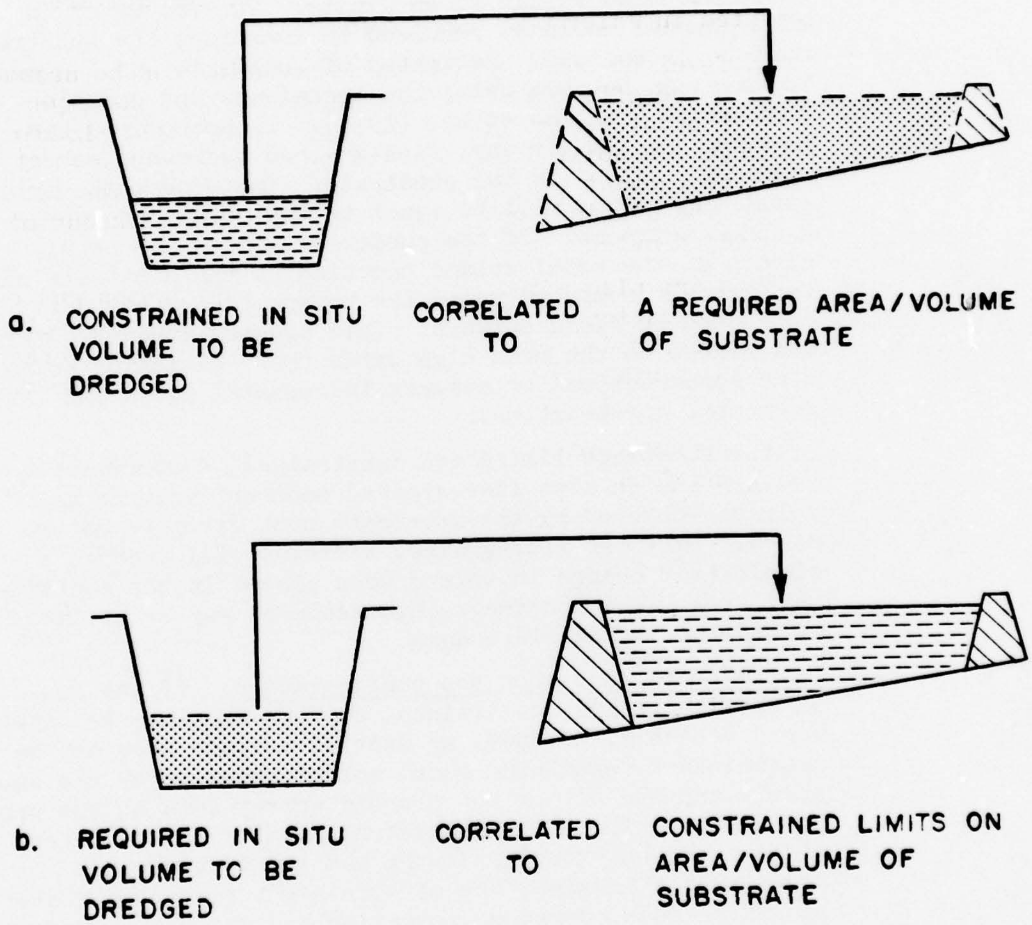


Figure 7. Correlations between channel and substrate volumes

found by dividing the total volume occupied by the substrate by the surface area.

d. Estimate settlements. Settlements of the substrate surface will occur following completion of the dredging operation due to self-weight consolidation of the dredged material layer and/or consolidation of compressible foundation soils. Settlements may be estimated by examination of the changes in void ratio due to the imposed loadings. Detailed procedures for estimation of settlements are presented in Palermo et al. (1978).

The self-weight loading of dredged material can be assumed equal to the effective stress at midheight of the layer due to buoyant weight of the overlying material. Loading of foundation soils is equal to the effective stress caused by buoyant weight of the entire dredged material layer. The loadings vary directly with the thickness of the dredged material layer.

Loadings are also affected by total ponding depths and by tidal fluctuations; however, the entire substrate should be assumed flooded to simplify calculations. The average dredged material layer thickness may be used in estimating loadings.

Time rates of consolidation for both dredged material layers and foundation soils are required to determine the relationship of substrate elevation with time. Consolidation-time data obtained from consolidation tests on channel sediment samples and foundation soils are used to develop the time rates of consolidation. Plots of the settlements versus time may then be constructed for each layer as shown in Figure 8.

e. Compare with elevation requirements. The settlement versus time data must be compared with elevation requirements for substrate establishment. The plot of average substrate elevation versus time may be developed using the settlement data as shown in Figure 8. The ultimate settlements at 100 percent primary consolidation can be used to estimate the ultimate substrate elevation. For one-time construction, these data may be directly compared with the MHW and mean low water (MLW) elevations and the time requirements for initial establishment of vegetation as determined by project requirements. For incremental construction, the data may be compared to the interim elevation requirements.

If the data reveal that settlement will not meet requirements for substrate establishment, an adjustment to the substrate configuration must be made. If settlement falls above elevation requirements, the initial substrate elevation at completion of dredging must be decreased. If

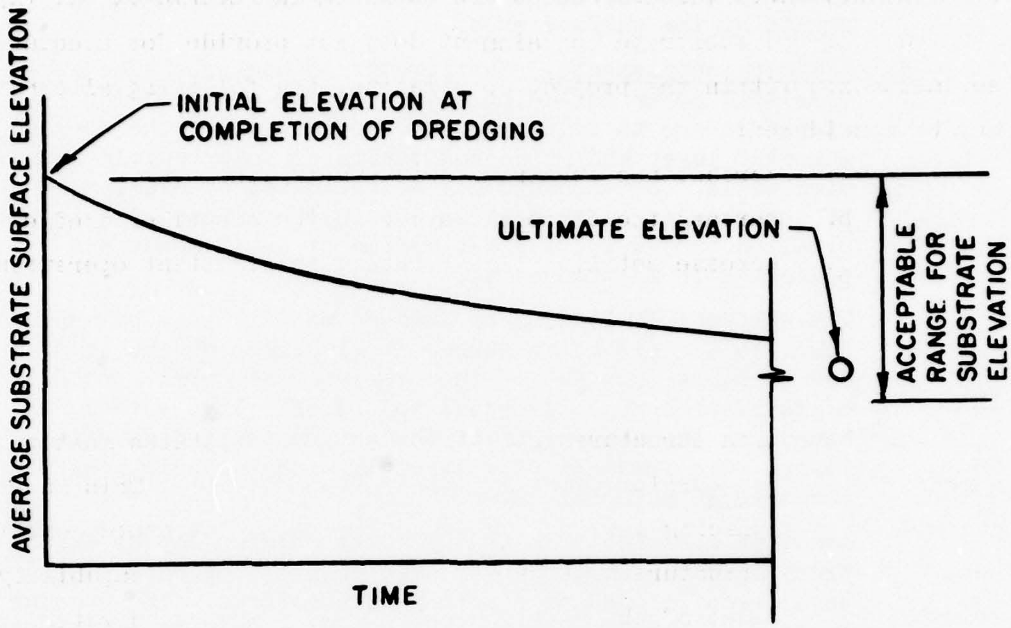


Figure 8. Dredged material substrate surface elevations versus time

settlement falls below elevation requirements, initial elevations must be increased. In the case of a constrained volume to be dredged, the proposed limits of the substrate may be adjusted. Settlement may then be recomputed and comparisons again made with elevation requirements. In this way, the optimum dredged material substrate elevation at completion of dredging may be determined.

Design for sedimentation

43. Confined substrates comprised of fine-grained dredged material must be designed for retention of the solids by gravity sedimentation during the dredging operation. Design for sedimentation is directly affected by size of the containment (area and volume), inflow rate (a function of the dredge size), operational conditions, physical properties of the sediment, and salinity of the dredging environment. Design procedures are available that provide for determination of the respective surface area or detention time required to accomodate continuous dredged material placement. Factors influencing hydraulic efficiency of the substrate containment must also be evaluated to include effects of short-circuiting, ponding depth, weir placement, and shape of the

containment. Detailed procedures are outlined in Palermo et al. (1978).

44. If the substrate containment does not provide for adequate sedimentation within the project constraints, the following alternatives may be considered:

a. Increase the substrate containment size.

b. Decrease the disposal rate by using a smaller dredge.

c. Increase settling time by using intermittent operations.

Weir design

45. Retention structures used for confined substrates must provide a means to release carrier water from the disposal site. This is best accomplished by placing a weir structure within the substrate containment. The weir structure must be designed to provide the capability of selective withdrawal of the clarified upper layer of ponded water within the containment without excessive resuspension and withdrawal of the settled solids. Weir design is based on the assumption that sufficient surface area or detention time has been provided for sedimentation and that short-circuiting is not excessive. Weir design procedures are described in Walski and Schroeder (1978).

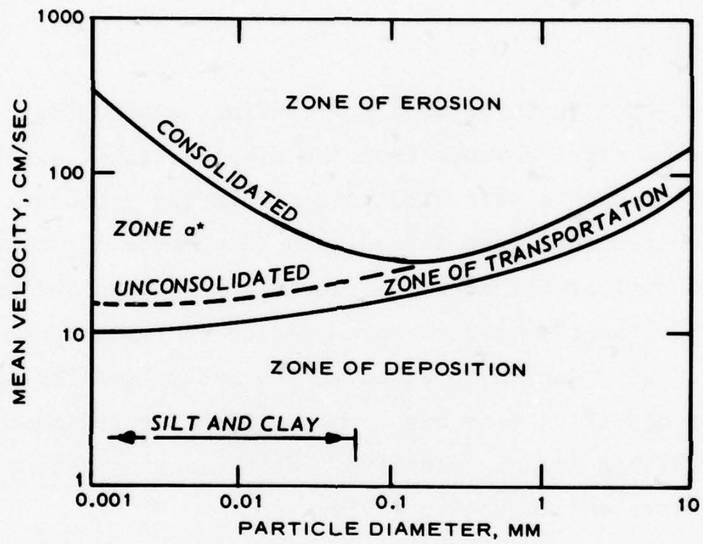
Guidelines for Substrate Retention and Protective Structures

Requirements for retention and protection

46. Site hydraulics and sediment properties determine the need for retention and protective structures at marsh development sites. These sites may require structural protection from erosion caused by currents, waves, or tidal action. A retaining structure may also be required to retain the dredged material until it consolidates and to control the migration of suspended fines. The first step in the selection of a retention or protective structure is to validate the requirement for such a structure. Particular concern should be given to the effects of any proposed structure on current or wave patterns. Structures which may

constrict water flow and increase local current velocities or reflect wave energy may increase erosion. Much of the discussion presented below is detailed in Eckert et al. (1978), which should be considered a principal reference.

47. The relationships between erosion, transportation, and deposition velocities and the sediment grain size are summarized in Figure 9. Values are based on velocities measured 15 cm above the bottom of a sediment.



*ZONE a = EROSION INFLUENCED BY DEGREE OF CONSOLIDATION.

Figure 9. Erosion-deposition criteria for different grain sizes (modified from Bass' and Bosco 1974)

48. The semi-empirical method described below may be used to approximate a design current velocity for comparison purposes (Johnson and McGuinness 1975):

- a. Estimate the maximum monthly surface tidal current at the site. This current might be obtained by reference to Tidal Current Charts from National Ocean Survey, by reference to past surveys, by simple surface observations during maximum monthly tides, or by estimation using professional judgment.
- b. Approximate the 10-year maximum based upon the reasonable assumption that the maximum velocities will be produced

a little before or after the maximum or minimum stage height. Stage height records are usually kept for bays, estuaries, and rivers in which major dredging projects are located. During the ebb flow from a maximum stage height, the water head must be dissipated. Under such circumstances, currents should be at or near their 10-year high. To estimate their horizontal velocity U , the following should be used:

$$U_{max_{10\ yr}} \approx \left(U_{max_{monthly}}\right) \times \text{(10-yr high water measured in metres above MLW)} \div \text{(monthly high water measured in metres above MLW)}$$

The current velocity $U_{max_{10\ yr}}$, may be used in conjunction with Figure 9 to determine if the sediments to be dredged will be subject to erosion and transportation, thereby requiring protection.

49. In general, substrates composed of fine-grained sediments will require a retention structure to reduce turbidity and to prevent excessive loss of fines during the dredging.

Structure selection considerations

50. Considerations in containment structure selection include the dredged material to be retained or protected, maximum height of dredged material above firm bottom, required degree of protection from waves and currents, permanence of the structure, foundation conditions at the site, and availability of structure material. These considerations will determine feasibility of a structure in relation to the project goal, the likelihood that the structure can be maintained over its useful life, and the structure's total cost. These factors are site-critical and require engineering site data.

51. Several retention and protective structure types are considered technically feasible for use in marsh habitat development and are illustrated in Figure 10. Their general applicability is summarized in Table 4. Two types of structures are likely to be used in habitat development projects:

a. Sand dikes. Sand dikes have long been the most common containment structure for confined disposal areas at both upland and in-water sites. The primary reason for their continuing appeal is their proven economy of construction.

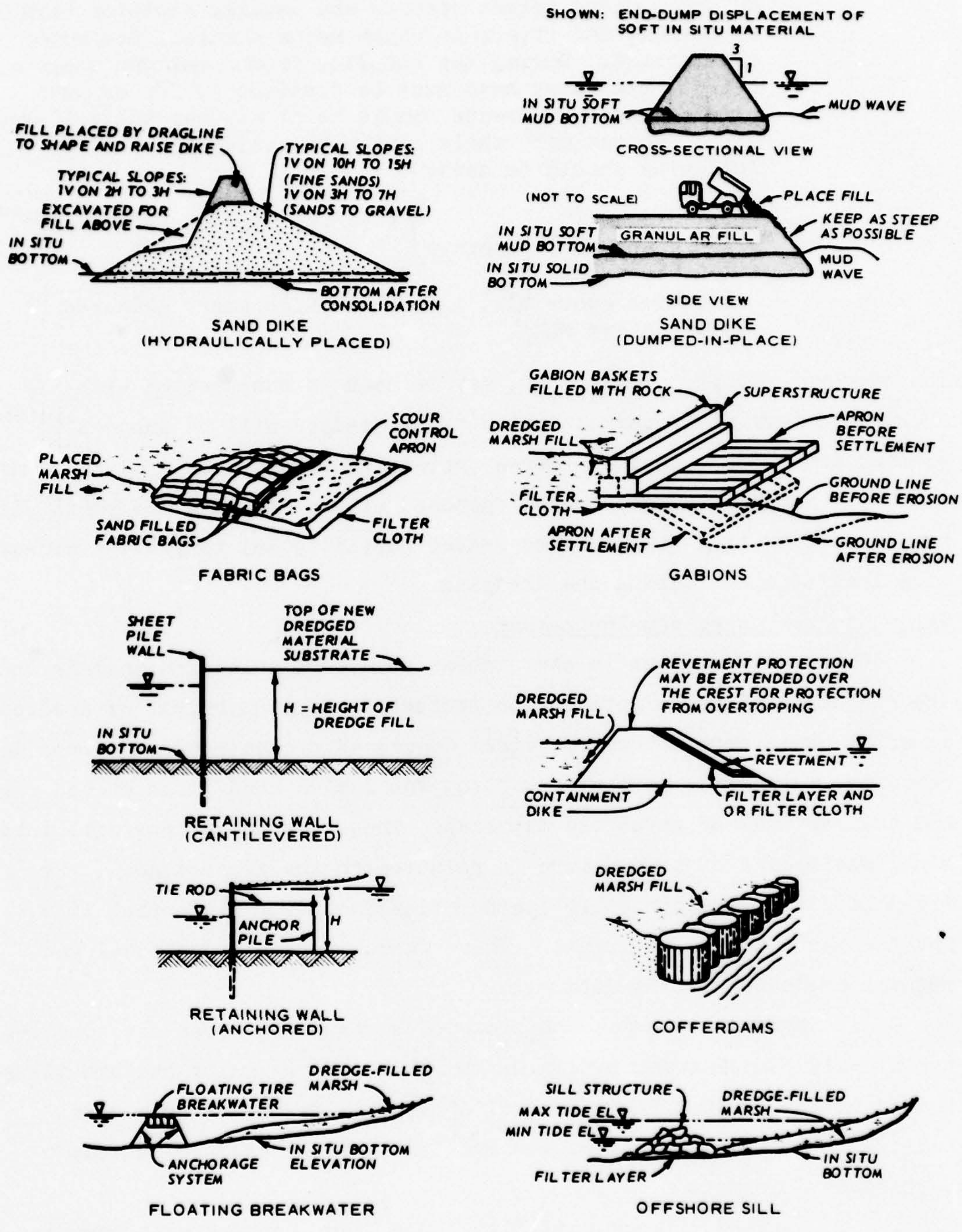


Figure 10. Retention and protective structures
(Eckert et al. 1978)

In 1974, a survey (Snethen and Patin 1974) found that dikes were used almost exclusively for in-water dredged material confinement. The Windmill Point marsh development site built by the DMRP used a sand dike (Figure 11) (Lunz et al. 1978b).

Because the sand dike is a gravity structure, it bears heavily on soft, relatively unconsolidated foundation soils typical of many potential wetland habitat sites. A major concern is the rapid increase in foundation loading that occurs while the dike is being built and dredged material is being placed. Stability of foundations with respect to shear failure is most critical at the completion of construction because strength of foundation soils is minimal. As the increased loading causes settlement, there will be an increase in foundation strength.

Dikes are usually overbuilt to compensate for settlement as the foundation soils consolidate. Their elevation is generally based on estimates of total expected settlement. Sand dikes can usually be easily upgraded to achieve necessary elevations. If the in situ foundation soils are of low strength, dike side slopes are usually flattened to achieve stability. A hydraulically placed dike will have very flat slopes that can be reworked by a dragline, or it may be left as a flat slope to accommodate a weak foundation. Very soft substrates can be mudwaved (progressively failed and caused to flow before the dike's advance). This method works best with end-dumped construction techniques, which permit steeper dike profiles than can be obtained with hydraulic fill methods.

Unlike dikes built at upland sites, dikes built in-water cannot be readily compacted to achieve greater stability, making the use of a relatively clean, free-draining, cohesionless sand desirable. If such material is available near the construction area, hydraulic fill with this sand is recommended. Other sources of sand include trucking sand to the site or obtaining it from borrow pits. If the dike is constructed in an area where its exposed surface must be protected from erosion by waves and currents, the slope of the dike should be revetted or riprapped. However, it should be stressed that the integrity of the revetment or riprap is dependent upon the stability of the dike upon which it rests. A filter cloth or filter gravel behind the revetment will help protect it from erosion.

b. Fabric bags. Any container filled with sand, sand-cement, or concrete that is used as building block material for breakwaters, groins, revetments, or containment dikes is considered a fabric bag for purposes of this discussion. The Wilmington District constructed two islands in Core

a. Hydraulically placed sand dike

b. Sand dike after shaping to improve elevation

Figure 11. Sand dike used to confine and protect fine-textured sediments at the Windmill Point site

Sound, North Carolina, using fabric bags; the Galveston District used large sand bags (Figure 12) to protect the DMRP field site on Bolivar Peninsula (Allen et al. 1978). Use of the bags is limited to areas that have access to heavy equipment, especially when fill material must be obtained on the site. Fabric bags should be filled with saturated sand, as tests reveal that air retained in voids causes a buoyant uplift force on the bags when submerged in water and reduces bag stability under wave attack (Snethen and Patin 1974).

Fabric bag dikes should be backed with filter cloth to prevent scouring and to insure that the dredged material is not lost through the openings between bags. The filter should pass under the base bag and extend up the back of the dike. If an apron is used to prevent scour in front of the dike, the cloth should extend under it as well. Fabric bag life expectancy is only 2 to 3 years, depending upon site accessibility to humans and subsequent vandalism, exposure to sunlight (ultraviolet rays degrade fabric rapidly), and energy forces exerted against the dike.

Design considerations

52. Elevation control. Final elevation of the substrate must be considered in the site design. As shown in Figure 13, the first step is to establish the desired elevation of the proposed marsh (a). Also shown in Figure 13 are anticipated foundation and fill consolidation to obtain maximum fill level (b), maximum ponding level (c), and theoretical maximum dike height of structure (d), which includes any additional freeboard that may be necessary to prevent overtopping. Allowances for retention structure settlement must also be considered. Elevation requirements may be determined using the following:

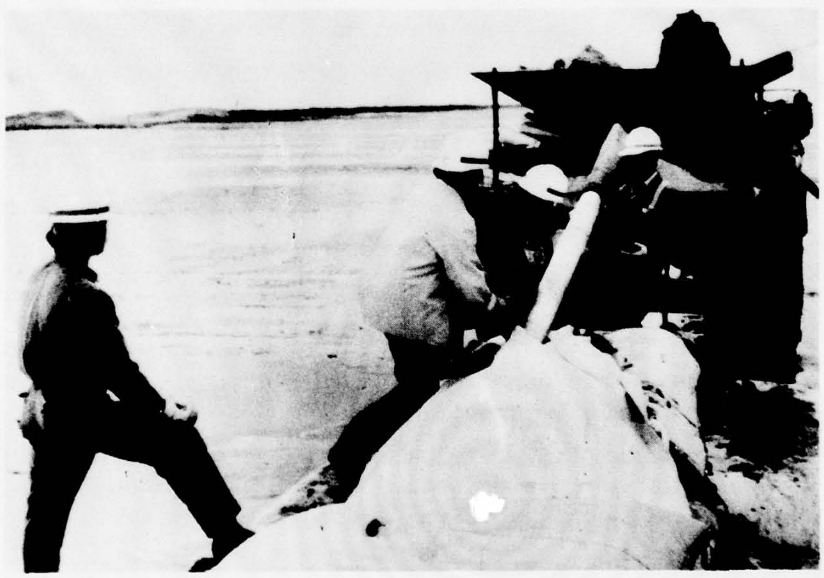
a. The desirable range of final elevations of the proposed marsh should be specified.

b. The maximum fill level should be determined based on correlation of in situ sediment and substrate volumes, the substrate configuration, and anticipated settlements.

c. The maximum ponding level should be established to allow for retention of suspended solids. A 0.6-m minimum ponding depth is needed.

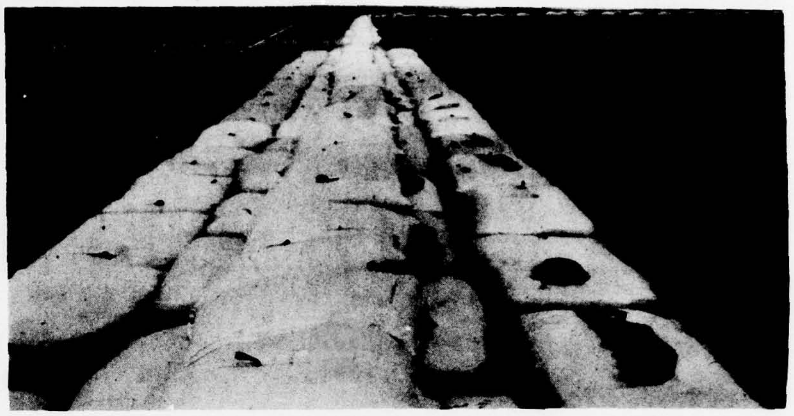
d. Freeboard requirements are based on susceptibility of the site to storm erosion and/or overtopping by waves or high tides.

a. Cloth bags are placed empty on filter cloth



b. Bags are filled with a sand slurry

Figure 12. Fabric bag dike used to protect sandy sediments at the Bolivar Peninsula site (sheet 1 of 2)



c. Newly completed dike

d. Dike after exposure to the elements for 2 years

Figure 12 (sheet 2 of 2)

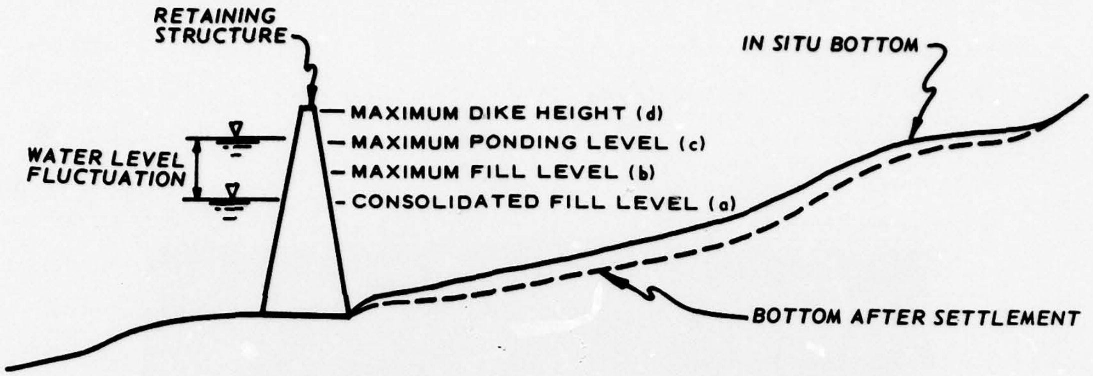


Figure 13. Definition of elevations
(Eckert et al. 1978)

53. Earth forces on containment structures. In the design of containment structures, all the water and earth pressure forces acting on the structure must be considered, as well as any surcharge that is anticipated during construction or in later use. New substrate which requires a retaining structure generally will be composed of soft clays and silts, which remain in a slurry state for a significant period after placement. A fluid pressure loading may be exerted on the retaining structure until the substrate begins to consolidate and develop shear strength.

54. The pressure time varies as the dredged material consolidates. The worst condition, which should be considered in design calculations, occurs during or immediately following the filling of the disposal site and is frequently termed "end-of-construction" case. As the retaining structure is being built, equal hydrostatic pressure acts on both sides of the structure. However, after placement of the dredged material has begun, an unbalanced force is exerted against the inside of the structure. This force is at a maximum when hydraulic filling has raised the contained material to the maximum design elevation, and the surrounding water level is at its lowest during low tide or low river stage (Eckert et al. 1978).

55. The pressure forces also vary with factors such as duration of fill, rate of filling, stoppages in filling, location and direction of pipeline discharge, and variations in grain size of the dredged

material behind the wall. While it is desirable to place the coarser textured material available directly behind the structure, this is frequently not feasible. Therefore, reasonable values of pressure loadings, based on reasonable field construction results, must be used in design calculations.

56. Wave forces on containment structures. Wind wave characteristics such as height, period, direction and the probability of occurrence can be found using locally collected data and hindcasting methods described in Chapter 3 of the Shore Protection Manual (U. S. Army Coastal Engineering Research Center 1977). At sites where wind waves appear to be a major consideration, early recognition of that fact may permit relocation or shifting of the site to reduce the open water fetch in the predominant wind direction, thus limiting the maximum wind generated wave. In shallow back bays and estuaries water depth will frequently limit the growth of wind waves (Eckert et al. 1978).

57. Because of the erosive effects of backwash on soft dredged substrate, wave runup and overtopping of a containment structure can be a major problem. Wave runup is dependent on several interrelated factors, each of which must be considered in establishing the safe height of the structure to prevent overtopping. The slope of the seaward face of the structure, the bottom slope and the water depth in front of the structure, the surface roughness of this structure, and the incident wave characteristics must all be considered in evaluating runup. With these design wave values, the wave-structure interaction can be predicted using methods given in Chapter 7 of the Shore Protection Manual (U. S. Army Coastal Engineering Research Center 1977).

58. Ship-generated waves may also be a major cause of erosion along the edges of marshes. Wave measurements properly timed to ship traffic at the dike site will allow establishment of a design value.

59. Erosion and scour. Erosion and scour involve the removal of soil particles by water action, above and below normal water surfaces. Erosion and scour can cause structural failure and must be guarded against by properly designed protective structures. The erosive ability of water waves and currents at a potential disposal site must be

considered in the selection and design of a retaining structure and its foundation. Using available empirical rules of sediment transport, a range of velocities can be developed that will indicate if erosion or scour is likely to be a problem. U. S. Army Coastal Engineering Research Center (1977) provides tables and charts of sediment motion initiation velocities and discusses their use. Detailed analyses of tidal and littoral currents and wave height production are also presented in that source.

60. Erosion can be minimized by proper location and orientation of the retention/protective structure. Locating the site in a low-energy environment is the ideal solution, and a must in many areas. Flattening the outer slopes of the fill or dike will reduce turbulence and scour. Streamlining the upstream face of the fill will also lessen erosion. Vegetation may be used to stabilize the dike and reduce erosion (see Part IV). Protection of inner and outer surfaces by the use of filter cloth, revetment, or antiscour blankets of rubble may be required in higher energy situations. Protection created by breakwaters or floating wave attenuating devices is also possible but may not be economically feasible (Eckert et al. 1978). Thorough discussions of site location, shape, and erosion control can be found in Johnson and McGuinness (1975) and in Hammer and Blackburn (1977). Design concepts for protective structures can be found in Eckert et al. (1978).

61. In riverine environments, an important consideration in determining water velocity must be the effect the fill placement will have on altering the flow conditions. When the fill decreases the cross-sectional area of a channel, there will be resulting increases in flow velocities and/or water surface elevations. These should be estimated and used to evaluate the erosion potential using methods described in Rouse (1950) and Vanoni (1975). Scour potential of the existing channel banks should also be examined if significant velocity increases are predicted.

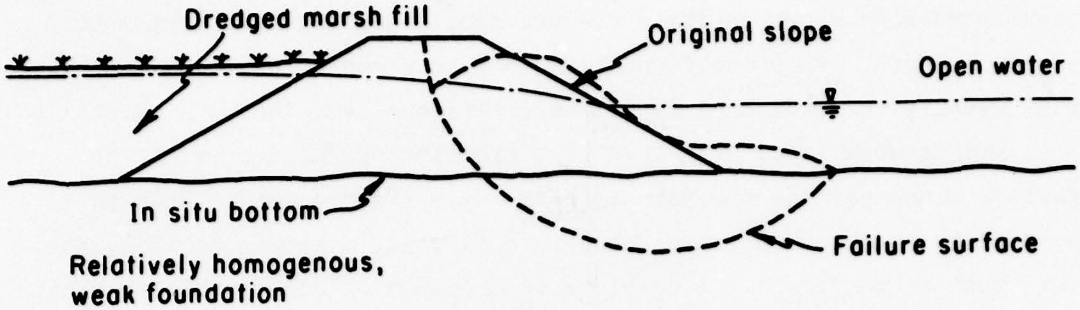
62. <u>Foundation stability.</u> The failure of an in-water retaining structure is usually the result of an overstress on foundation materials. Clays and silts most frequently found in the types of bottom areas

associated with marsh habitats are unconsolidated and have very little shear strength. When the foundation soil is homogeneous, this failure will usually be rotational in character (Figure 14a, 14c). A stratified soil with a weak layer will lead to a translating failure, with the failure plane passing through the weak layer (Figure 14b). When an earth dike or other retaining structure is used, a slope stability analysis must be performed. A complete description of dike stability as it applies to confinement structures is contained in Hammer and Blackburn (1977).

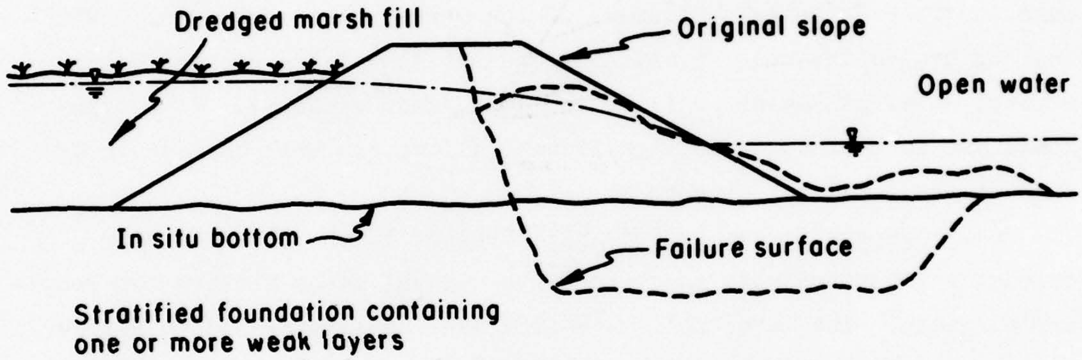
63. Foundation settlement. Evaluation of the foundation soil's bearing capacity, the stress distribution caused by the retaining structure, and the expected settlement of the structure is essential. Methods for evaluating bearing capacity and settlement are presented in Office, Chief of Engineers (1958 and 1953, respectively). If settlements are determined to be significant, allowances must be made in design of the retaining structure.

64. Seepage forces and piping. Seepage is the flow of water through a saturated soil mass caused by unequal heads between two boundary surfaces. The water follows a flow line as illustrated in Figure 15. The amount of water which flows in this matter depends on the head differential and permeability of the material through which the flow takes place. In-water dikes will normally need to be constructed from coarser grained materials, which typically have a high permeability, and may require seepage protection by graded gravel filters or filter cloth to avoid erosion of the dike (Figure 15b). If water flow is sufficient to remove the sand at a point on the downstream boundary surface, head loss is gradually decreased and erosion retrogresses through the embankment like an ever-enlarging pipe.

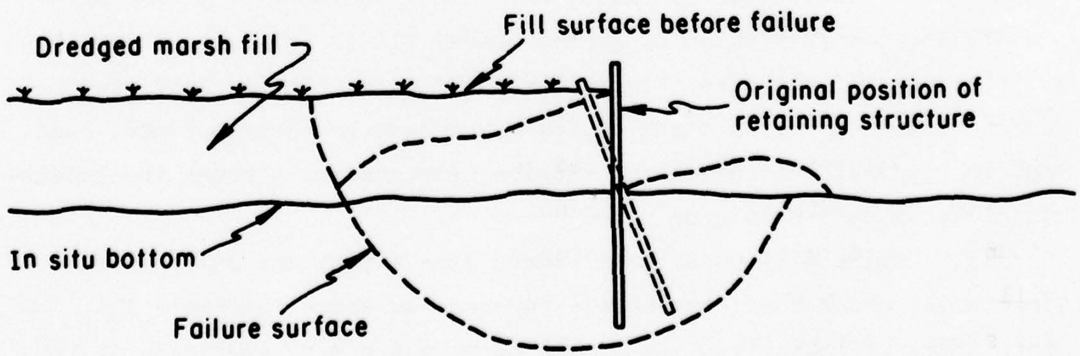
65. Uplift will occur under these same situations when the flow lines exist under some structural component as shown in Figure 15a, where there is zero effective stress between the sand particles at the toe of the dike. If the sand at the base of a structure becomes fluid, both lateral and vertical strength are lost, and major failure can result.



a. Rotational Failure in Dike and Foundation

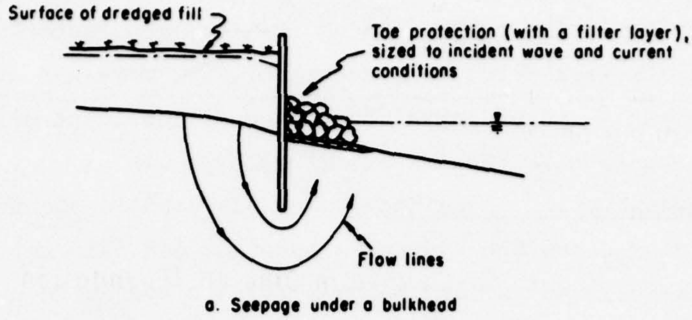


b. Translatory Failure in Dike and Foundation



c. Rotational Failure Involving Fill and Retaining Structure

Figure 14. Examples of typical slope failures
(Eckert et al. 1978)



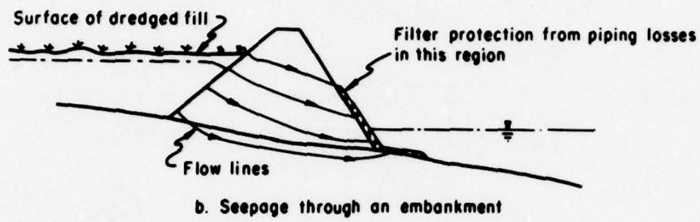


Figure 15. Seepage flow paths (Eckert et al. 1978)

66. Retention structures for dredged material will probably not require control measures for seepage and uplift since the head differential will rarely exceed 3.3 m. Seepage control normally consists of increasing the length or the resistance of a flow line and sizing the material at the seepage discharge point to resist piping. If control should be necessary, methods include the use of an impermeable plastic membrane on the inner dike surface or the use of a filter cloth on the outer surface under a protective layer of riprap or other revetment. The former method will greatly reduce seepage and the latter will prevent piping of dike soils. Increasing the length of flow lines by widening the dike crest, flattening outer dike slopes, or by other means will reduce both the quantity and the velocity of seepage. Techniques for seepage analysis and control are presented in Office, Chief of Engineers (1952).

Construction considerations for retention/protective structures

67. Site characteristics. Characteristics of the site will

determine which construction techniques are feasible and greatly influence construction costs. Among the location factors that influence costs are: equipment accessibility, wave and current conditions, tide range, water depth, bottom conditions, and distance from the dredging site (Eckert et al. 1978).

68. Construction techniques. Methods used in constructing in-water retaining dikes are hydraulic pumping, end-dump methods, and dragline or clamshell (Murphy and Zeigler 1974). Hydraulic pumping of materials is an economical method of establishing a large volume dike section. In general, the wide hydraulic fill section is constructed to an initial height above the surrounding water. The upper portion of the dike is then shaped with draglines or other equipment using the coarse-grained materials that are generally provided from initial hydraulic construction.

69. End-dump construction of dikes may be accomplished using suitable borrow material transported by truck. This procedure requires that embankment construction begin adjacent to land and progress outward as a haul road is established. Material dumped from trucks is then pushed into the water and shaped by bulldozer. In some situations, dikes may be constructed with a clamshell or dragline from material taken from within the containment area. This also gives the added benefit of increasing the storage capacity of the site.

70. Construction techniques for retaining walls, sills, breakwaters, gabions, and other structures are highly site-specific and should be evaluated using design procedures recommended by Eckert et al. (1978). Equipment normally required for dike construction and surface shaping is presented in Table 5.

71. Construction control. Thorough inspection of all construction operations will insure that work is being done in compliance with plans and specifications and will point out details not adequately prepared for. In most cases, construction crews and inspectors will not be familiar with the details of a marsh development project. Past experience has shown that the importance of adequate inspection cannot be

overemphasized. The success of marsh development depends on correct final elevation, slope, and circulation patterns.

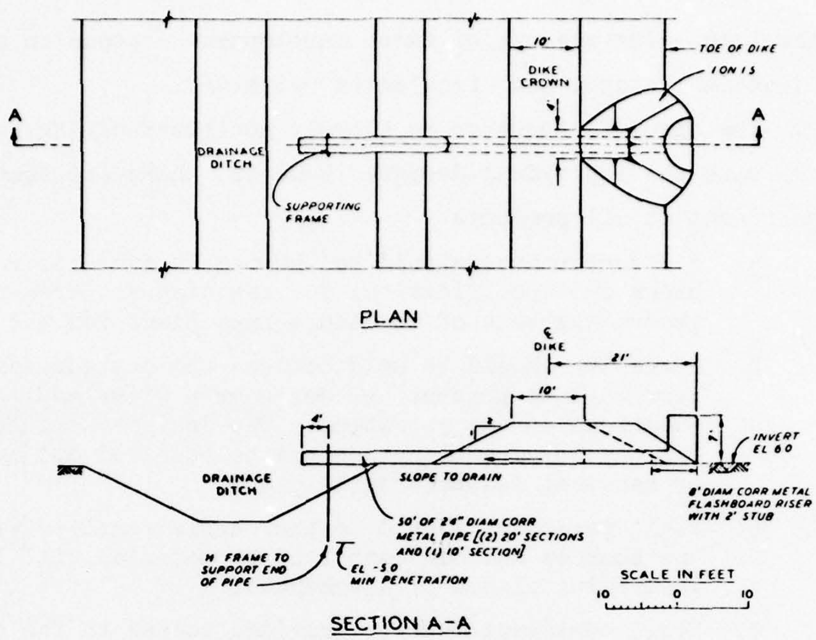
72. The specific items to be closely monitored during construction will vary with the individual design. However, there are some general items pertinent to all projects:

- a. Field personnel should be thoroughly familiar with the plans and specifications for the disposal area and with general aspects of the long-range plans for the area.
- b. A meeting should be held between the designer and field personnel to present the designer's views and resolve questions on the operation. The designer should point out any key items that should be observed and any unusual or marginal features anticipated.
- c. Field personnel should be thoroughly familiar with the borrow sources and how each type of material will look when being placed or discharged.
- d. Field personnel must be provided access to the construction area at all times and should be on hand continuously during construction.
- e. Complete written and photographic records of all operations should be maintained.

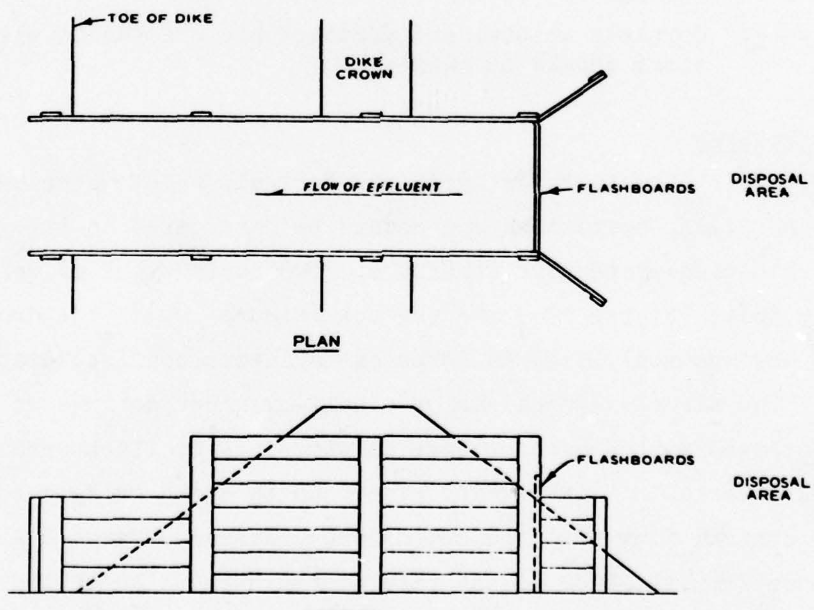
Weir structures

73. Weir structures are required for release of water during and after the filling operations and should be considered an integral part of the retention/protective structure. Two basic types of weirs are the drop inlet (Figure 16a) and the box (Figure 16b). The drop inlet weir is most commonly used in Corps of Engineers confined disposal operations. The structure consists of a half-cylinder corrugated metal pipe riser equipped with a gate of several stop-logs or flashboards that serve as a variable height weir. They can be added or removed as necessary to control flow into and out of the containment area. A discharge pipe leads from the base of the riser through the dike to the exterior.

74. The box weir consists of an open cut through the entire dike section. The cut is usually lined with timber but could be lined with concrete or steel. Box sluices also use stop-logs for controlling drainage. Box sluices are not often employed because of two reasons: susceptibility to failure caused by seepage and subsequent piping along



a. Typical drop inlet weir structures



b. Box weir or flume (reproduced, with modification, with permission from Hydraulic Dredging by John Huston, Copyright 1970 by Cornell Maritime Press, Inc., Cambridge, Md.)

Figure 16. Basic types of weirs

the dike-sluice contact, and the high construction costs where dike sections are wide. Box sluices are capable of rapidly discharging large volumes of water. This feature could prove advantageous in marsh establishment since natural water level fluctuations throughout the containment area may be necessary during construction and are essential to the natural operation of the new marsh. Additional information regarding weir design, construction, and operation can be found in Hammer and Blackburn (1977), Palermo et al. (1978), and Walski and Schroeder (1978).

Guidelines for Dredged Material Placement

Dredged material placement operations

75. Dredging and transport operations. Material may be placed within the substrate using either hydraulic or mechanical methods. The hydraulic pipeline dredge is by far the most commonly used method and will provide the major source of material to be used for marsh establishment. Pipeline length can be extended to several kilometres with the addition of intermediate booster pumps, but at a substantial additional cost (Johnson and McGuinness 1975). Hydraulic transport of material assumes additional prominence when one considers that the newer concepts for dredged material handling systems involving direct pumpout of bucket-loaded scows usually involve final disposition via pipeline. The pipeline dredge can dispose of material in shallow water areas through the use of shore lines or shallow-draft floating pipelines (Johnson and McGuinness 1975).

76. Obtaining select material. The structural characteristics of dike material can be a critical factor in the success of a marsh establishment project. Knowledge of the available materials is of considerable importance. Making maximum use of the coarse-grained material available within the waterway to be dredged will probably result in the most economical method of removing it, a task that must be completed anyway. Coarse-grained material encountered during dredging operations can be taken advantage of with end-of-pipe operations. If the character of the sediment-water slurry being transported is known

beforehand or can be determined by monitoring at the dredge or at the end of the pipe, then the coarse material can be diverted to the desired location by use of a wye connection without interrupting the dredging operations or the dredging sequence. The diverted material can be placed directly in the desired location via hydraulic fill or stockpiled for later use. Stockpiling and subsequent rehandling of material is roughly equivalent to obtaining the material from another source outside the disposal area and involves the use of additional or supplementary equipment.

77. Material placement operations. Depending upon the character of the dredged material, the nature of the disposal site (confined or unconfined), and the potential for adverse environmental impacts, a range of operational procedures can be used for material placement to insure the ultimate success of a marsh development project. Significant advantages will accrue in marsh building if measures are taken to control the location and distribution of the coarse- and fine-grained fractions of the dredged material within the substrate. For example, the long-term stability of the marsh can be enhanced by placing the coarse-grained material on the side of the marsh facing towards the direction of maximum erosive energy.

78. A means for maintaining control over the distribution of material is to take advantage of the settling characteristics of the various sized particles in the dredged slurry. Coarse-grained material settles more rapidly than does fine-grained material. Evidence of this natural classification process is the buildup or mounding of coarse-grained material near the end of the discharge pipe. The fine-grained particles are carried farther away and settle in quieter, less turbulent waters.

79. For the majority of dredged material disposal projects, the criteria for location of the discharge pipe in the disposal area have been to maintain an adequate flow distance relative to the weir, to keep the discharge end of the pipe a safe distance away from the interior slopes of dikes, and to minimize the pumping distance from the dredge. These criteria are directed at preventing short-circuiting or channelization of the flow through the containment area, avoiding

scouring damage to dikes, and minimizing pumping costs.

80. Some modification of the above pipe location criteria may be required if advantage is to be taken of the natural particle size classification process. An illustration of the concept is to position the end of the discharge pipeline at the edge of the substrate most prone to erosion forces.

81. Pipe movement operations on water. The use of floating pipelines is a particular advantage in shallow water areas. Placement of the pipeline can be done during periods when water depth is greatest, thus avoiding the limitations of land-based vehicles in marshy areas (Johnson and McGuinness 1975). The minimum depth of water in which the pipeline will float can be reduced through the use of larger flotation pontoons or their equivalent. The pipeline should be flexible to permit the dredge to advance without having to move the pipeline each time; this is achieved by use of elbows and swivels. The discharge end of the pipe can be maneuvered in various ways. For open-water placement or in confined areas, the discharge can be redirected by moving anchors that hold the pipe in place.

82. Greater flexibility of pipe movement on water has been achieved through the use of a spillbarge (Figure 17) when conditions permit. The spillbarge is commonly used when the dredged material disposal area is located adjacent to the channel being dredged. Booms up to 77 m long have been used to dispose of dredged material over a dike, linear island, or jetty located parallel to the channel being dredged. The spillbarge is maneuvered behind the dredge as it moves along the channel. No additions or deletions of pipeline sections are necessary and continuous disposal is possible. A uniform or linearly dispersed distribution of material within the disposal area can be achieved depending upon the rate and direction of movement of the spillbarge (Johnson and McGuinness 1975). In some instances, a uniform aerial distribution of material over the disposal area is desired. The placement of a sand layer may be required in order to improve the trafficability of the disposal area surface or to provide a drain to relieve pore pressure under a dike or within the fill (Johnson and McGuinness 1975).

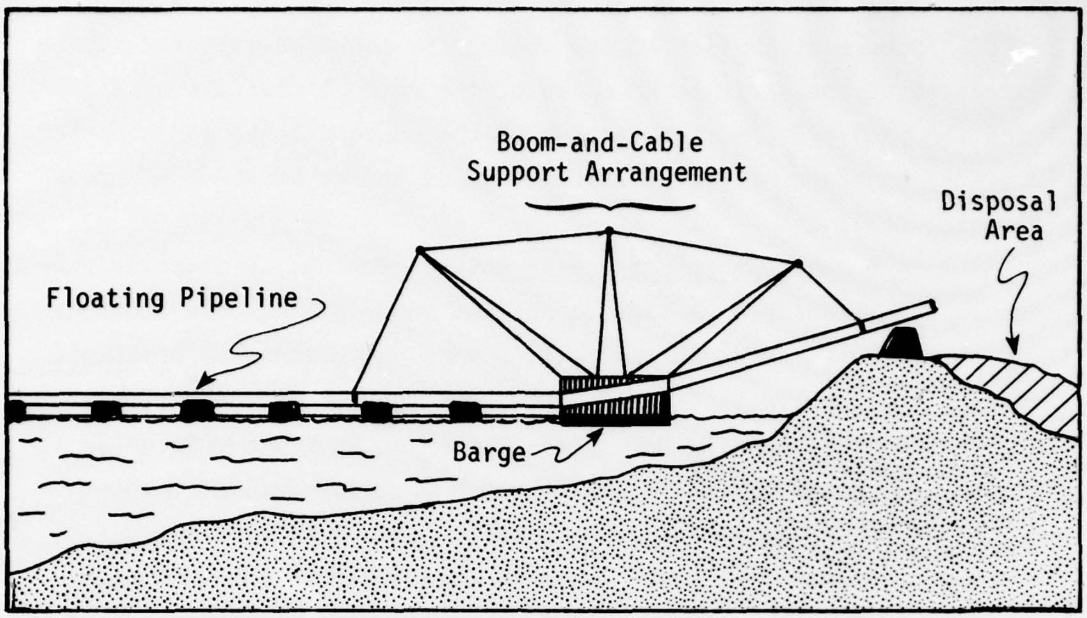


Figure 17. Sketch of spillbarge (Johnson and McGuinness 1975)

83. Pipe movement on land (shore line). Pipe sections for use on land are usually held together by welding flat metal strips across the joints or by tying wires on cleats. Because of this and the heavy weight involved, the shore line cannot be easily moved. Directional changes of pipelines are made by using special fittings with 30°, 45°, or 90° elbows (Johnson and McGuinness 1975).

84. Material placement flexibility for a shore line is achieved through the use of wye branches and valves which are controlled with gate or swing valves that switch the flow from one pipe extension to another. If discharged material mounds near the end of one pipe, the flow can be diverted to the other pipe, and the mounded area leveled or the pipeline extended. This allows continuous dredge operation. On stable soils this operation can be done by heavy equipment; on unstable soils, it must be done by hand labor, usually a crew of 4 to 6 men (Johnson and McGuinness 1975). The use of timber mats or marsh buggies sometimes helps extend the range of equipment operation capabilities.

85. Energy dissipators. These are used to reduce the velocity of the dredged material slurry at the discharge pipe. The energy from the

slurry flow can scour and resuspend already deposited material and can damage the interior slopes of diked areas. This can be of benefit in redistributing mounded material; however, the scouring action generally leads to channelization and short-circuiting of flow (Johnson and McGuinness 1975). Three primary kinds of energy dissipators are used:

a. Baffle plates. The baffle plate is located at the end of the discharge line and is commonly mounted at an angle to the flow direction. It spreads the flow over a wider area and reduces erosive force.

b. Wye joints. A wye joint at the end of the discharge line can effectively double the area of flow and thereby halve the velocity. An extension of this method is the placement of a sand layer using a branching pipe system. Care should be taken in designing and constructing the pipe distribution system so that velocities are adequate to transport the material. This can be accomplished by using branching lines of a smaller diameter than the main pipe (Johnson and McGuinness 1975).

c. Bleeder pipes. Dike construction in both underwater and on-land situations has been accomplished using a bleeder pipe, which contributes both to a classification of material and a reduction of the discharge velocity. This involves the elevation of the end section(s) of the pipe on *H- or X-cribbing.* The bleeder pipe has holes cut into the underside of the pipe that allow heavier material to drop out, letting fines flow on past and out the main disposal pipe. The bleeder pipe can be equipped with movable gates over the hole to regulate flow.

86. Operational guidelines for placement in confined substrates. Operational practices suggest several guidelines applicable for confined substrate placement. These guidelines are:

a. Position the discharge pipeline so that the coarse fraction of the dredged slurry will be deposited on the erosion-prone side of the marsh.

b. Ease material placement operations on water by using:

(1) Additional pipeline flotation.

(2) Spillbarge.

(3) Floating swing-discharge line.

c. Ease material handling operations on land by using:

(1) Wye branches and valves with pipeline.

(2) Fill trafficability improvements.

(3) Whooping crane.

(4) Low-ground-pressure vehicles.

(5) Dragline with deadman and pulley.

d. Lessen scouring of disposal area materials by using energy dissipators such as baffle plates, bleeder pipes, and pipe distribution systems.

e. Maintain adequate detention time for sedimentation in confined disposal areas by using:

(1) Properly designed weirs with adjustable crest elevations.

(2) Spur dikes if required.

(3) Adequate ponding depths.

f. Divide substrate area into cells so that:

(1) Flexibility in receiving incremental fill volumes is increased.

(2) Accuracy of settlement prediction in filled cells is improved.

(3) New marsh can be developed incrementally.

87. Influence of placement on retaining structures. Proper placement of dredged material presupposes a knowledge of the engineering properties of the material being dredged. The coarser grained dredged material may be utilized as dike material or placed behind the containment structure as appropriate. The soft cohesive soils are generally deposited away from these structures. This selective placement improves the stability of the containment structure (Eckert et al. 1978).

88. Quality of final dredged material soils can be improved by careful placement of the discharge pipe and grading of the site. Further discussion of this technique can be found in Turnbull and Mansur's (1973) review of several hydraulically placed fills.

Management activities for confined substrate placement

89. Placement of dredged material within a confined area is identical with placement in any other containment area. Certain management activities are therefore necessary to assure that suspended solids are retained within the area and that effluent quality is maintained. More

detailed information regarding management of dredged material containment areas is found in Bartos (1977) and Palermo et al. (1978).

90. Surface water management. The management of surface water can be accomplished by controlling the elevation of the outlet weir(s) throughout the operation to regulate the depth of water ponded within the containment area. Proper management of surface water is required to assure containment area efficiency and can provide a means for access by boat or barge to the containment area interior.

91. At the beginning of the placement operation, the outlet weir is set at a predetermined elevation that will insure that the ponded water will be deep enough for settling as the containment area is being filled. As the operation begins, slurry is pumped into the area; no effluent is released until the water level reaches the weir crest elevation. Effluent is then released from the area at about the same rate as slurry is pumped into the area. Thereafter, the ponding depth decreases as the thickness of the dredged material deposit increases. After completion of the placement operation and of the activities requiring ponded water, the water is allowed to fluctuate with the tides through the existing weir structure.

92. Use of the ponded water for floating the pipeline within the containment area can be of benefit to general containment area management by greatly facilitating the movement of the inlet point without disruption of the dredging operation. The floating inlet allows selective placement of coarse-grained material behind the retention structure or at desired mounding locations within the substrate.

93. Ponding of sufficient water permits access, by boat or small barge, to the interior of the containment area. This allows access for sampling or installation of any necessary instrumentation during the placement operation. The depth required for this purpose is determined by the draft of the vessel used.

94. Suspended solids monitoring. A well-planned monitoring program during the entire dredging and decanting operation is essential to assure that effluent suspended solids remain within acceptable limits. Since suspended solids concentrations are determined on a gram per litre

basis, requiring laboratory tests, it is desirable to complete a series of laboratory tests during the initial stages of operation. Indirect indicators of suspended solids concentration such as visual comparison of effluent samples with samples of known concentration or use of a properly calibrated hydrometer may then be used during the remainder of the operation, supplemented with laboratory determination of effluent solids concentrations as needed for record purposes. Additional guidance on suspended solids monitoring and description of test procedures are presented in Palermo et al. (1978).

95. Postdredging activities. Once the substrate has achieved the desired degree of stability and after careful consideration of the erosion potential of such an action, the weirs or retention structure may be breached to allow natural water circulation throughout the substrate area.

Surface shaping operations

96. Upon completion of the disposal operation, the surface of the fill may need to be shaped or graded in order to meet final elevation requirements, to improve water circulation, or for other reasons. In many cases coarse-grained material may be graded using heavy equipment; however, it is likely that fine-grained fill material will not support tracked vehicles, such as bulldozers, and the distance to the center line of the disposal area may preclude the use of a conventional floating dragline. The operational range of tracked vehicles and draglines can be extended through the use of matting or the building of finger roads. This requires frequent moves and can add significantly to the cost and time of the grading operation. In these situations the use of low-ground-pressure vehicles, such as marsh buggies, may be adequate to complete the job.

97. More likely, a highline arrangement could be used. It would employ a winch, a deadman at the opposite side of the disposal area, and a dragline bucket as shown in Figure 18. The deadman is required so that the cable to which the bucket is connected can be pulled back and forth over the area being graded. Portable dredges using this technique have been used with bucket capacities of approximately 3, 6, and 10 m

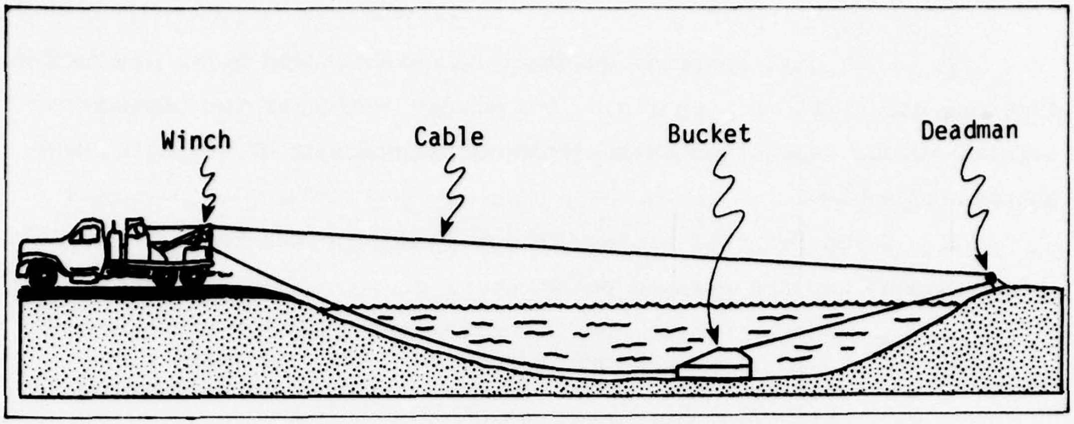


Figure 18. Portable dragline with tail support (Renfrue 1971)

and over distances of up to 500 m. Requirements for the deadman have been satisfied using small trees, a dozer, or the equivalent (Renfrue 1971).

98. In some instances the operational range of floating draglines or clamshell dredges can be extended by digging access channels into the fill area. These access channels could be left upon completion of the project and, if properly developed, would aid in improving water circulation in the new marsh.

99. The narrower a given area of marsh is, the easier the eventual task of reworking the surface with equipment to meet biological preferences, such as improving drainage, providing a network of access channels, and removing or creating interior mounds and holes.

Substrate surface trafficability

100. Access to the substrate area for surface shaping operations or for planting activities will be necessary in many cases. The extent to which such activities may be performed is dependent upon the availability of equipment or vehicles which can successfully operate on the newly placed dredged material substrate. Guidelines are contained in Willoughby (1978) for characterization of soil conditions and vehicles and predictions regarding trafficability. Based on these characterizations, a particular piece of equipment can be selected for a given set of conditions, or limiting conditions can be determined for a specific piece of equipment.

PART IV: PLANT PROPAGATION

101. This part contains guidance on establishing marsh vegetation once the substrate is prepared. It includes design of the propagation effort, actual vegetation establishment, maintenance of the site, and potential problems.

102. Seven forms of propagules are available for marsh vegetation establishment and are defined below:

a. Seeds. These are the common reproductive structures of most plant species. Seeds are found on marsh plants singly, in clusters, in pods, and on multistemmed or single-stemmed seed heads.

b. Rootstocks. Rootstocks are the root system of a plant including that small portion of stem normally below ground. The propagule may be divided into sections or clumps for planting; new growth will generate from the old root systems.

c. Rhizomes. This propagule is similar to rootstocks and refers to underground stems that usually grow horizontally. The rhizomes are dug and divided into sections, taking care to keep at least one viable growth point (meristematic tissue) on each to ensure new growth.

d. Tubers. Tubers are large fleshy underground stems often associated with rhizomes. They should be dug near the end of the growing season to obtain the new crop for planting. Tubers for some species, such as chufa, may be harvested mechanically. Others, such as saltmarsh bulrush, must be harvested by hand. Except for chufa, marsh plant tubers are usually difficult to obtain.

e. Cuttings. Cuttings are made of sections of the top shoots of a plant, taking care to obtain nodes in the section. In the case of woody marsh species such as willows, cuttings should be made 0.3 to 0.6 m long from the end of a branch or twig of 1-year-old growth. Cuttings of some herbaceous marsh species can be taken from any section of the top shoots (with nodes); when planted shallowly on the site, new growth will occur. Smartweeds, glasswort, and a few other herbaceous species that have quick regenerative abilities can be propagated readily from cuttings.

f. Seedlings. These are young plants with weakly developed root systems. They may be obtained by digging the seedling from a stand in the natural marsh or germinating seeds in a greenhouse and growing them to seedling stage. This technique is frequently used with smooth cordgrass, which, in commercial greenhouse operations, is readily grown from collected seeds.

g. Transplants (sprigs). This is by far the most common and most successful propagule type for marsh establishment projects. This propagule is the entire plant dug and removed from a natural marsh and transplanted to the new site. The term sprig generally refers to smaller transplants, often very young, which are obtained in the same manner. It is best to leave marsh soil with the transplants when they are dug to minimize shock from root loss and disturbance. Plants dug during the dormant (winter) season usually suffer less from stress and shock than those dug in the late spring and summer. The transplant should be as large as is practical to work with. Since plant material is often obtained by hand labor and is hard to transport, a suggested size for transplants is not over 10 to 15-cm-diam root clumps with top shoots of a compatible size.

Planting Design

Factors influencing design

103. The successful establishment of a planned marsh requires careful project design and implementation. Each site will exhibit its own peculiarities and must be approached individually. In any marsh design a number of factors are significant; the most important are discussed as follows:

a. Salinity. Most plant species are not salt tolerant; therefore, only those species known to tolerate the tested salinity of the dredged material substrate and the water source should be planted on any given site. Approximate salt tolerances of marsh plant species are given in Table 6.

b. Tidal range. In a tidewater area, species planted should be adapted to specific site conditions. For example, smooth cordgrass, a species known to tolerate frequent inundation, would be planted at the lowest elevations. Saltmeadow cordgrass and saltgrass, species that tolerate less frequent inundation, would be planted inland of the smooth cordgrass at a higher marsh elevation.

c. Flood stages. In interior lake, stream, and river areas, the season and duration of periods of flooding and drought must be considered in planting design. Problems encountered include seasonal or man-induced water level fluctuations which may dessicate or drown the plants or erode the site. Moisture tolerances of marsh plant species are given in Table 6.

d. Soil texture. The texture of the dredged material will significantly influence the physical and chemical properties of the soil and may exert a governing influence on the success of plantings. For example, coarse-textured soils may be nutrient poor and consequently not support vigorous plant growth.

e. Wave and wind action. Wave and wind action will influence planting design. A stable substrate is necessary for successful plant establishment, and this may require location of the project in a low-energy site or provision of structural protection.

f. Contaminant tolerance. Dredged material may contain contaminants such as heavy metals, pesticides, and petroleum products. Little work has been done on tolerance of marsh plants to these contaminants; however, very few of these substances have actually been shown to be limiting to plant growth. The potential for plant uptake and release of contaminants into the environment is a related problem of greater concern than contaminant tolerance (see paragraph 151).

g. Outside influences. Disturbance to a site can be caused in many ways. Waves from passing boat traffic may uproot young plants and cause erosion. Washing of debris onto the site may damage even mature plant communities. Excessive early use by wildlife, such as goose grazing of smooth cordgrass roots, may destroy an ongoing project if not controlled.

h. Cost. Costs are often the deciding factor in determining whether to pursue habitat development or to allow natural colonization and succession to occur on the site. The planting design should be realistic in terms of available funds. Section 150 of Public Law 94-587 now provides authorization for funding marsh habitat development projects in conjunction with Corps dredged material disposal projects.

Protection

104. The newly planted substrate must be protected either by virtue of its location in a low-energy area or by placement of a protective structure such as a permanent or temporary dike (Figures 11 and 12). Low-energy areas are most commonly found in the lee of beaches, islands, and shoals; in shallow water where wave energies are dissipated;

on the convex downstream side of riverbends; in embayments where marshes presently exist; within zones of active deposition; and away from long fetch exposure, tidal channels, uncontrolled inlets, and headlands (Johnson and McGuinness 1975). Protective structures were discussed further in Part III.

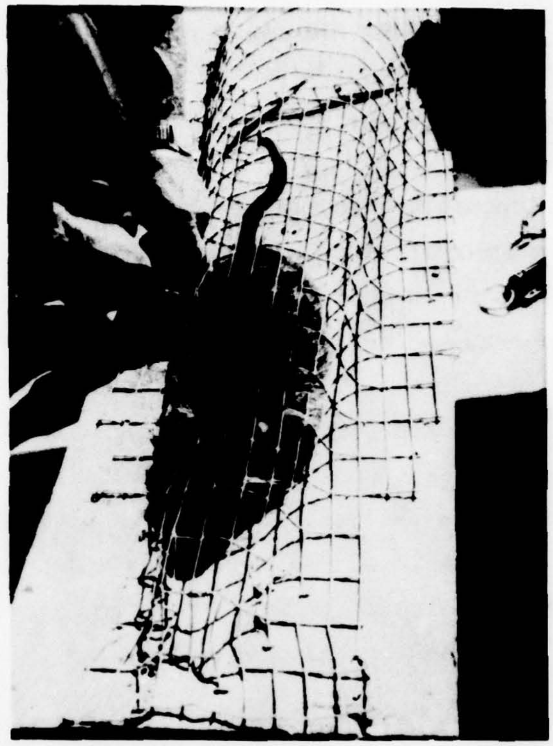
105. Plants themselves may be used as a protection barrier by planting more erosion-resistant large transplants on the outer fringes of the marsh, with more susceptible but less expensive propagules such as rootstocks, tubers, and seeds in the interior and high marsh areas of the site.

106. Young plants are particularly vulnerable to wildlife depredation. Herbivores such as Canada geese, muskrats, nutria, rabbits, goats, sheep, and cattle can rapidly destroy a newly established marsh. Heavy grazing may even destroy mature marsh communities. Potential animal depredation should be evaluated for each site and in extreme cases should be controlled by trapping or fencing (Figure 19).

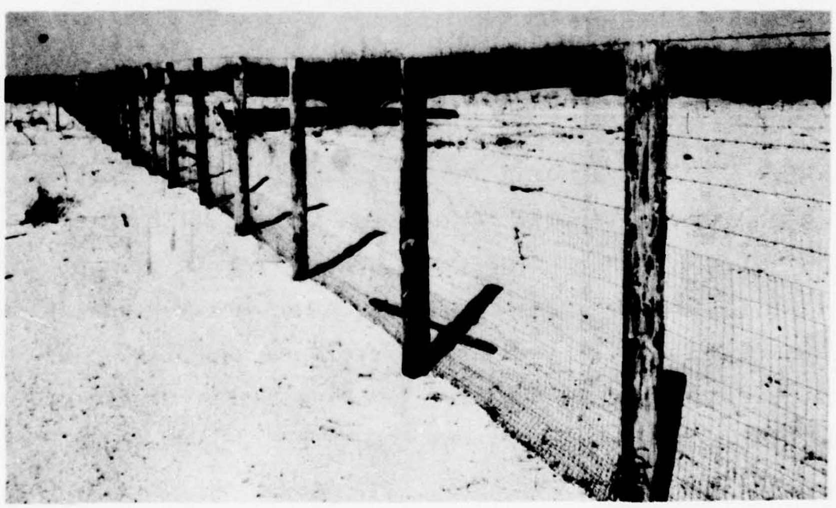
Plant spacing

107. Plant spacing is highly site-specific and is governed by the quality of the substrate, type of propagule, length of the growing season, and desired rapidity of plant cover. Generally, when transplants are used, parallel rows and spacings of 0.3 to 1.5 m are recommended to achieve relatively uniform cover by the end of the second growing season (Figure 20). Planting at about 1-m intervals is usually a good compromise between high costs and full cover. If the cost of transplants is a limiting factor, or there is no compelling reason to attain full cover within a short time, then spacing may be greater than 1 m. If the site is extremely unstable, subject to heavy wildlife pressures or physical stresses, or if aesthetics are an immediate concern, more dense plantings may be desirable. For example, if Canada geese are known to use the area heavily, the plants should be spaced closely to encourage the geese to limit their feeding to the edges of the new marsh (Garbisch 1977). Transplants may be evenly or randomly spaced; even spacing is more efficient in use of machinery and labor.

108. Other vegetative propagule types such as rootstocks, rhizomes,



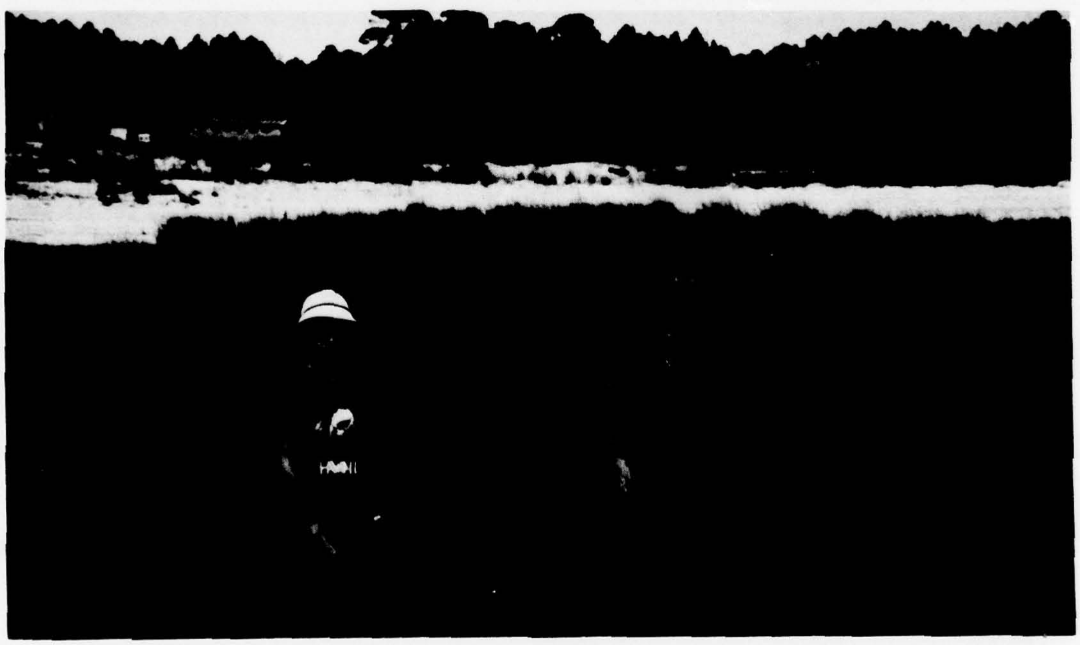
a. A nutria removed in a trapping program at Miller Sands



b. A fence erected at Bolivar Peninsula to exclude cattle, goats, and rabbits

Figure 19. Techniques to protect young plants from animal depredation

a. Sprigs at 1-m intervals 1 year after planting



b. Growth after 2 years

Figure 20. Saltmeadow cordgrass marsh development at the Apalachicola Bay site. (Note building in background for relative reference point)

and small sprigs are handled similarly to transplants. However, since they grow much slower initially, these propagules should be spaced more closely. Intervals of 0.2 to 0.5 m are recommended for rootstocks and rhizomes, and 0.5 m for small sprigs.

Diversity

109. In general, a site planted to a variety of species over a topographic range, from deepwater to upland areas, is preferred. Exceptions to this are sites where physical stresses are particularly harsh or stabilization is critical (as on dike slopes), where only one species can tolerate the conditions, or where quick cover by a vigorous monoplanting is needed. More typically, variation in site elevation with respect to water regime will necessitate planting the dredged material with at least two species to obtain both high and low marsh.

110. Species diversity can be used to achieve several objectives:

a. Appeal to a more diverse group of wildlife users of the site.

b. Enhance habitat for a target wildlife species that prefers mixed or patchy habitat for its life requirements.

c. Control animal depredation by planting a high-value wildlife food species as a sacrifice.

d. Better insure site success; if one plant species does not establish, another one of the selected species may be successful and establish the habitat.

e. Provide for long range plant succession at the site by making available sources of several desirable species.

111. An example of planting for area diversity is provided by the San Francisco Bay Conservation and Development Commission (1966), which proposed the following minimal criteria for Pacific cordgrass development on the west coast:

a. At least 5 percent of the site should be exposed at high tide.

b. At least 20 percent of either the new marsh or the surrounding area should provide mudflat exposure.

c. At least 10 percent of the site should be suitable for Pacific cordgrass.

d. At least one major pool or lagoon should occur in each unit area.

e. The remainder should be determined by site-specific circumstances and needs.

112. These criteria reflect the importance of open areas in a stand of vegetation. In San Francisco, the Commission had observed birds feeding on the mudflats. In a northern cattail marsh, Weller (1975) recorded that a 50:50 cover:water ratio was most productive of waterfowl. It may be necessary to first establish the marsh, then do any clearing that may be required for a wildlife enhancement objective.

Vegetation Establishment

113. Once a dredging project with appropriate marsh habitat development considerations has been designed, and while the engineering aspects are being carried out, preparations should begin for actual planting of the site. Such determinations as species selection, best propagule size and type, collection techniques, handling and storage techniques, planting techniques, and individual problems related to each species must be made before actual vegetation work can begin. Considerable time is involved in locating, obtaining, and preparing for transplanting appropriate propagule types, sizes, and numbers. Sufficient lead time is also needed for seed propagules since an obligatory seed-ripening period is usually necessary after harvest.

Plant species selection

114. The selection of plant species appropriate to the region, to the site, and to the project objectives is the first step toward vegetation establishment. Success of the project may hinge upon the species being planted, propagule types used, and the use of the plant material by wildlife. The site planner should familiarize himself with nearby marsh plant communities that occur on similar sites, noting the distribution and relative abundance of species within the stands. All species should be considered. Smooth cordgrass, because of its large areal extent, has been considered the major marsh species in the eastern United States. But the significance and productivity of other species

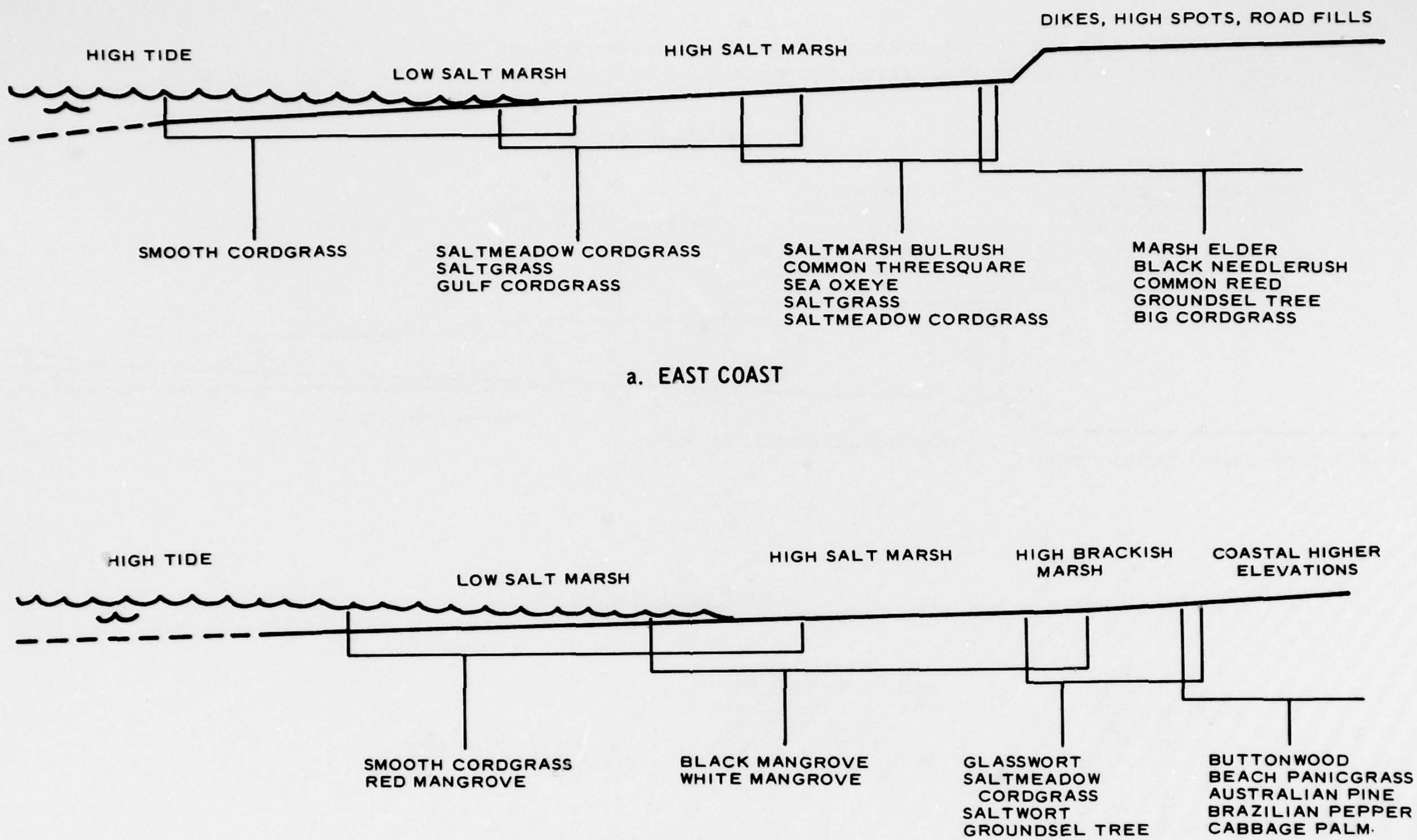
such as black needlerush, saltgrass, and saltmeadow cordgrass, previously considered minor, have been documented by Gosselink et al. (1977) and Reimold and Linthurst (1977).

115. It is suggested that a listing of those plant species occurring in the region and their specific associations be made. This listing can then be reduced to those suited to the site based on the factors discussed on the following pages. The reader is referred to the Wetland Guide series (Environmental Effects Laboratory 1978, Environmental Laboratory 1978a, 1978b, 1978c, 1978d, 1978e, 1978f, and 1978g) for typical community composition of various marsh types that may be found in the United States. Figures 21-24 show generalized profiles of major marsh plant associations for east and west coast salt marshes, brackish marshes, and fresh lake, pond, and river marshes.

116. Appendix C is a synopsis of 28 of the more commonly planted marsh plant species including description, range, habitat, associated species, establishment techniques, value, tolerances, and pertinent comments for each. Table 6 lists 115 marsh species typically occurring in fresh, brackish, and salt marshes within each of six geographical regions. The table is not all-inclusive but provides a general guide to common marsh species. It shows geographic ranges, soil conditions (pH, salinity, texture), moisture requirements, morphology, potential pest species, soil stability values, and wildlife value (food, cover, nesting/breeding). Table 7 gives recommended propagules and general collection, handling, and planting techniques for those 115 species, as well as pertinent remarks not shown elsewhere.

117. There are many species of plants that are suitable for planting marsh development sites. In addition to the ones listed in Tables 6 and 7, there are other species of unknown tolerances and adaptability which may prove, after testing, to be useful on dredged material. Selection of a species or mixed group of species for planting at a particular site should be based upon the following considerations:

a. Project goal. The goal of the project, i.e., aesthetics, wildlife enhancement, mitigation, substrate stabilization, etc., should already be determined. Only those plant



a. EAST COAST

b. FLORIDA (SOUTH)

Figure 21. Sketches of typical east coast and Florida tidal marshes showing plant associations and usual occurrence in the marshes

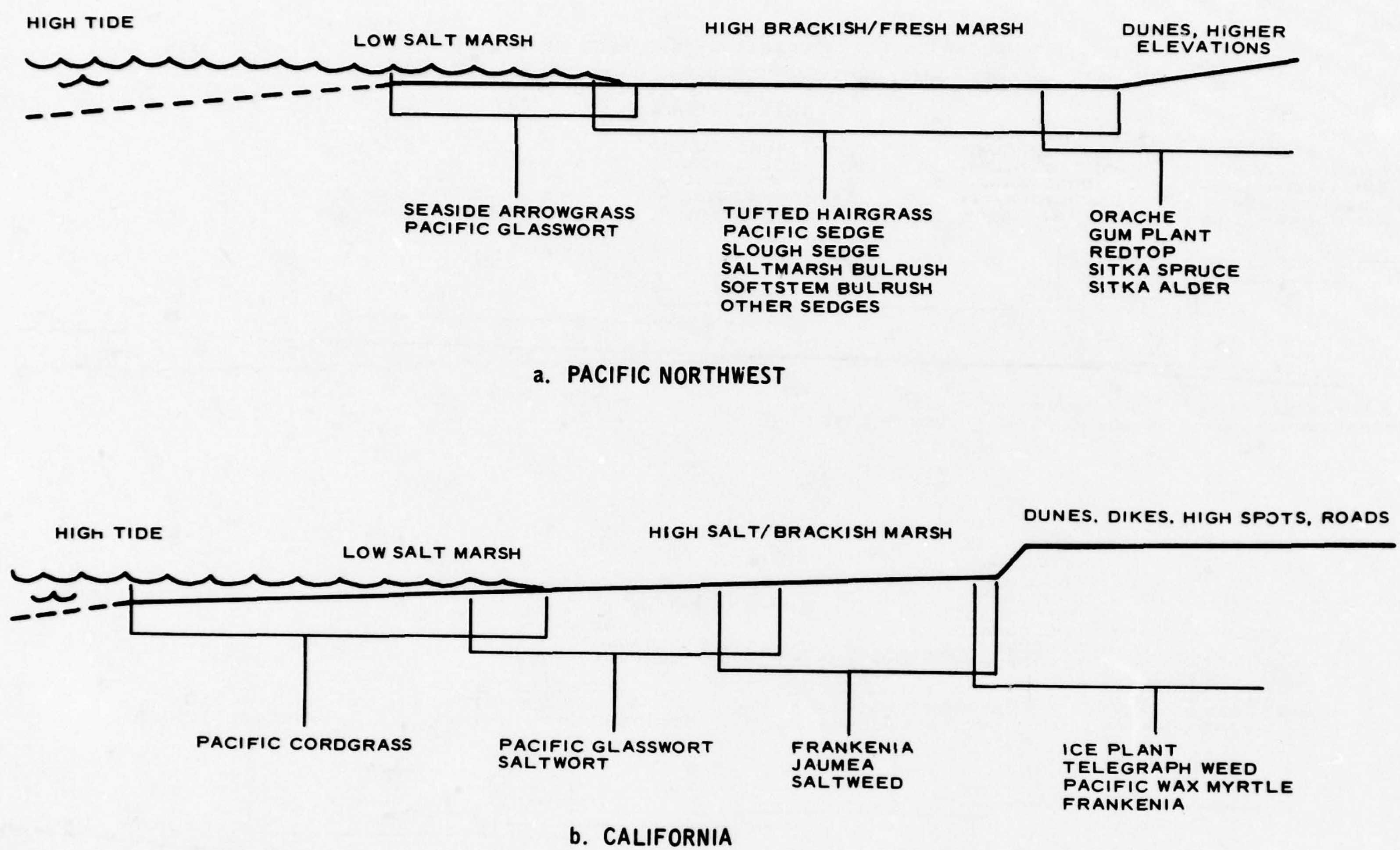
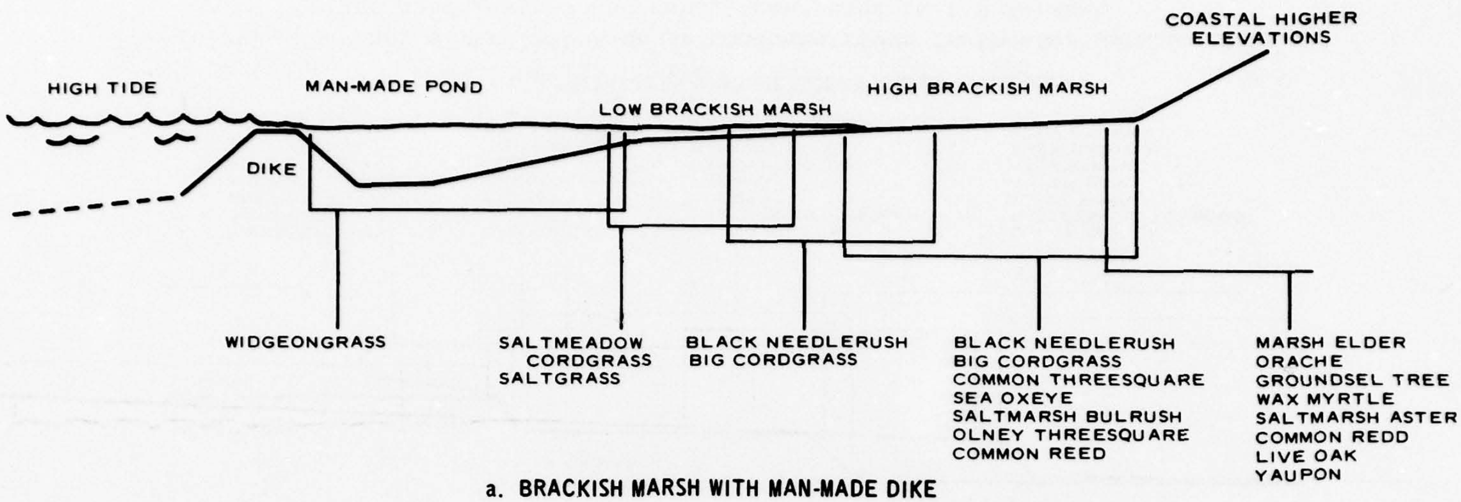
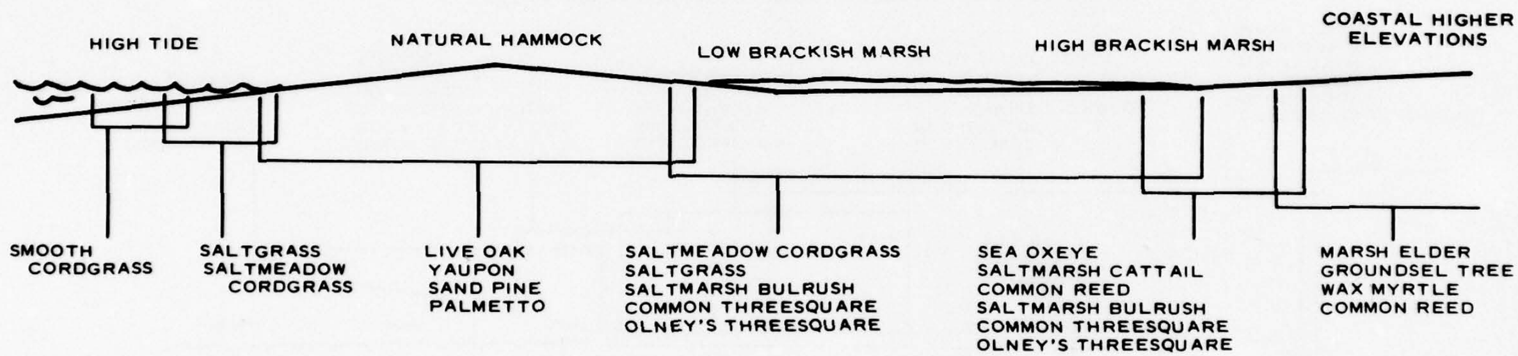


Figure 22. Sketches of typical Pacific Northwest and California Coast tidal saltmarshes showing plant associations and usual occurrence in the marshes

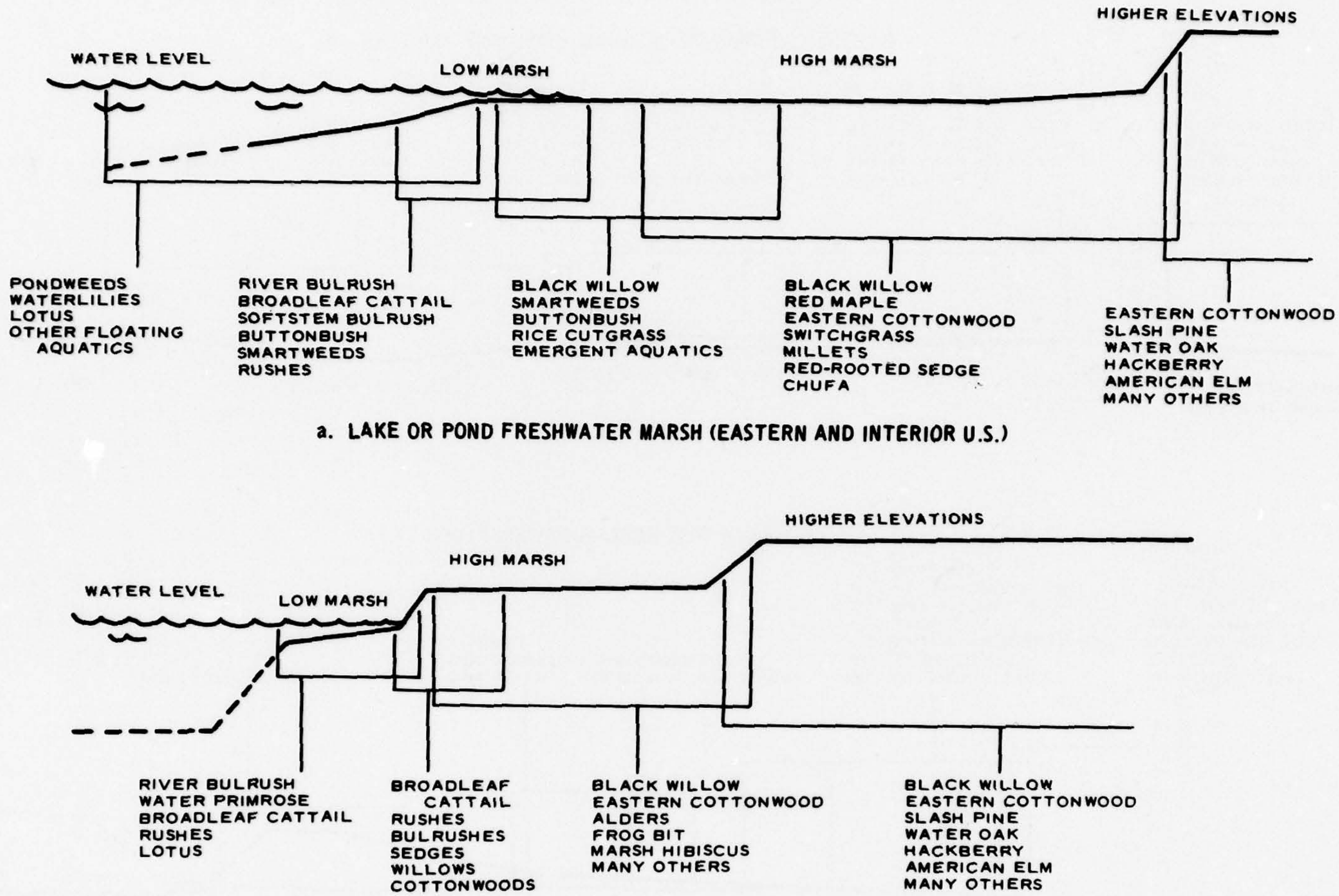


a. **BRACKISH MARSH WITH MAN-MADE DIKE**



b. **NATURAL BRACKISH MARSH WITH HAMMOCK ISLAND**

Figure 23. Sketches of typical brackish marshes, showing plant associations and usual occurrence in the marshes



a. LAKE OR POND FRESHWATER MARSH (EASTERN AND INTERIOR U.S.)

b. RIVER FRESHWATER MARSH (EASTERN AND INTERIOR U.S.)

Figure 24. Sketches of typical lake or pond and river freshwater marshes showing plant associations and usual occurrence in the marshes

species that satisfy the project goals should be considered.

b. Location. In most situations it is desirable to select plant species that are native or common in the general geographic location of the site. Exotics should be introduced only if there is assurance that they will not become nuisance species.

c. Climate and microclimate. Plants will not survive and reproduce unless adapted to local climatic and photoperiodic conditions. It is highly desirable to use local plant sources, from less than 160 km distant.

d. Tolerance. Tolerance to salinity, water level fluctuation, heat or cold, sun or shade, various water and soil conditions, and competition from other species will affect a plant species survival and reproductive capacity.

e. Soil characteristics. The plant species must be able to survive, grow, and reproduce under the influence of soil conditions of the site. Soil texture, moisture-holding capacity, fertility, pH, salinity, contaminants, and the presence of unusual features common to dredged material such as desiccation cracks, clay balls, and assorted debris from the disposal pipe are all factors that will play a role in a plant species success.

f. Growth characteristics. Several growth characteristics must be considered in plant selection.

(1) Can the species successfully compete with other planted and native species? If so, will it inhibit other desirable species?

(2) What is the life expectancy (annual, perennial, biennial)?

(3) Will the plant cover be established as rapidly as desired?

(4) Will the plant species reach optimum size within a reasonable length of time?

(5) Will it reproduce successfully, either by seed or vegetatively, so as to maintain a viable population and site cover?

(6) Will it stabilize the substrate to prevent erosion?

(7) Is it resistant to insect pests and diseases?

g. Availability. Selection of a species often must be based upon availability. There may be numerous species that are acceptable, but that are not obtainable because of time, economic, or manpower limitations. This is especially true if the plant species is not commercially available, if it must be harvested by hand labor, or if its seeds cannot be used as propagules.

h. Maintenance. Careful, intensive, and frequent maintenance after initial site preparation and planting is costly and manpower-intensive. Species that are selected should be hardy and able to survive with minimal care. Maintenance activities not considered excessive could include:

(1) Weeding or mowing of undesirable competing species that invade the planted area in early stages.

(2) Postpropagation fertilization of the plant material.

(3) Protection by fencing and other barriers from wildlife grazers until establishment is assured.

i. Costs. Regardless of what other attributes a species has, if obtaining and planting the propagules cost more than the project can afford, it is not a desirable species. Costs are generally lower if a commercial propagule source is located. Costs will generally increase in proportion to the amount of hand labor required.

118. If a project goal is to establish habitat for target wildlife species, any plant species known or suspected to be of use for cover, food, resting, or nesting for those species should be considered. Martin et al. (1951) is a reference for plants having wildlife food and cover value. Bellrose's (1977) waterfowl book is a comprehensive summary of life requirements of waterfowl species. Landin (1978) and Soots and Landin (1978) are sources of habitat needs for colonial waterbirds. Hunt et al. (1978) present wildlife food values for many species and the extent of their use by wildlife. The Journal of Wildlife Managment and other natural resource periodicals are also pertinent.

119. If soil stabilization is a goal, species selection will be influenced. Marsh plant species have varied capacities for stabilization (Cole 1978, Gosselink et al. 1977). Their underground root structure, rate of growth, and season of growth enter in. Gosselink et al. (1977) hypothesized that a species with a longer growth cycle, such as saltmeadow cordgrass, probably is more effective at erosion control than one such as big cordgrass, with a seasonal cycle. Lewis and Lewis (1977) demonstrated the value of planting fast-growing smooth cordgrass

to stabilize a site for mangrove propagules.

Propagule selection

120. Once species selection has been completed, more detailed consideration must be given to the type and availability of plant propagules, the amount of plant material needed to propagate a site, and the costs. The criteria for selection of propagule types are similar to the considerations used for selection of plant species. There are six:

a. Availability and costs. When more than one propagule type is acceptable and is available for a species, a balance must be reached between availability, cost, probability of success, and ease of handling. Often time constraints will limit availability of a propagule because the biological cycle of reproduction does not coincide with the dredging project. This is especially true with seeds. Frequently, even though a species normally reproduces by seeds, the seeds will not be available due to poor seed production or heavy predation. The least risk alternative, transplanting, is also usually the most expensive, while the least expensive, seeding, carries the greatest risk.

b. Collection and handling ease. A propagule must be easy to locate, obtain, and handle. Seeds, seedlings, and some transplants may be available commercially. When they are not, there may be problems such as:

(1) Obtaining enough seeds from plants in natural stands to plant a new site. Viability and percent germination of marsh plant seeds are often low. For example, smooth cordgrass seed heads are often infected with a fungus that renders them unusable.

(2) Obtaining sufficient quantities of vegetative propagules without causing significant damage to the donor marsh.

(3) Digging many pieces of plant material and keeping them alive until time to plant on the site. To plant most sites, several thousand propagules will be needed.

(4) Transporting large amounts of plant material from the marsh, to and from the storage areas, and back to the new site.

(5) Inexperienced or unwilling field labor. An experienced nursery staff may increase production significantly.

(6) Storing and handling the propagules. This includes

such tasks as separating rhizomes and tubers, removing seeds from seed heads and clusters and cleaning them, and potting transplants prior to transfer to the site.

c. Storage ease. Seeds do not normally present a storage problem since they are usually kept in a cool room or refrigerator at temperatures from 1° to 5°C. Seeds of most marsh plant species must be stored in water, either fresh or brackish, to prevent desiccation or premature germination. They may require treatment with pesticides and/or fungicides to prevent seed loss. All these factors will have a bearing on the germination success of the seeds when they reach the site. Vegetative propagules are more of a problem to store in that:

(1) Space in a nursery or greenhouse area is needed to hold the plants for the site.

(2) Labor must be hired to water, fertilize, and maintain the plants until planting.

(3) Plants will need to be potted in suitable field containers or placed in nursery soil beds to ensure maximum survival. If peat pot transplants are to be used, potting medium must be purchased or dug.

d. Planting ease. Seeds can be broadcast or planted in rows by machine or by hand. Some vegetative propagules may be planted by machine but usually they must be hand-planted.

e. Disease. Often plant sources will be infected with fungus or viral diseases, thus limiting propagule selection. Neither vegetative propagules nor seeds should be taken from an infected stand.

f. Urgency of need for vegetative cover. The selection of a propagule may depend on the urgency of the need for vegetative cover. In highly visible sites or sites subject to erosion, it may be necessary to establish a plant cover as soon as possible. Other sites may not require plant cover for several years. The most rapid and effective technique is use of transplants.

g. Elevation of the site. Garbisch (1977) recommended more mature propagules at decreasing elevations to increase probability of success, with exceptions in the litter deposition zone and in high elevations of areas with high tidal amplitude.

The advantages and disadvantages of the various propagules are given in Table 8.

Handling plant material

121. Seeds. The collection, storage, and handling of seeds frequently requires specialized techniques. Propagation by seeding is not recommended unless experienced personnel are available for consultation. Useful techniques for handling marsh plant seeds are presented by Kadlec and Wentz (1974), Maguire and Heuterman (1978), and Ternyik (1978). A general discussion of seed handling follows; however, the reader is advised to obtain details on selected species prior to implementation of the project.

122. When seeds are not available for commercial sources, they must be collected from natural stands. Locate plant stock that is readily accessible, fairly abundant, disease-free, and that is producing a current season crop of seeds. Several locations may be necessary for collection of the numbers needed to avoid depletion of a natural stand. Collect seeds when they are mature but not shattering out of seed heads or off clusters. Depending upon the species and the region, this period could vary from April to November. Remove the seeds by cutting off the entire head or cluster in the field and taking it back to the laboratory for threshing. Fleshy seed heads should be thoroughly dried before threshing. Clean chaff and infertile seeds from seed lots by sieving and/or blowing while threshing out seeds.

123. Seeds should be tested for viability and germination at the beginning of storage and again prior to planting to determine quantities of seed needed, as these percentages may change over a period of weeks. Store seeds according to known information. When in doubt or if data are not available, it is suggested that seeds be stored in fresh water at 5°C in open containers to allow ventilation. Seeds should be checked frequently for fungus or rotting. Seeds of many salt marsh plants will germinate at 5°C if placed in fresh water. These seeds should be maintained in brackish water (at least 10 to 15 ppt) then rinsed with fresh water before planting. Care should be taken not to place seeds susceptible to salinity damage in brackish solutions; the whole seed lot could be lost from improper treatment.

124. Before planting, some seeds may require special treatment

such as scarification of hard seed coats to induce germination. This is especially true of rushes and bulrushes. Viability tests may be made by a variety of methods (Maguire and Heuterman 1978, U. S. Department of Agriculture 1961); tetrazolium staining is the most common.

125. Vegetative propagules. Unlike upland and agronomic plant species, only a few marsh species are generally available from commercial sources as transplants and other vegetative propagules. Therefore, details of collecting and handling plants from natural stands are given here. Locate plant stock that is readily accessible, fairly abundant, and disease-free. Collection methods vary depending upon the propagule selected, but in general it is best to collect propagules while the plant is dormant. Alternative times are at the beginning or at the end of the growing season. Plants that are seeding or fruiting should not be collected as they are under stress from this reproduction phase and will be more likely to go into shock and die than a vigorously growing, nonseeding plant. Collect propagules from natural stands where, during the growing season, plants show indications of vigor and health (good color, no dead material, signs of reproduction). To minimize damage to the donor marsh, patches no larger than 0.1 m should be dug, widely spaced to prevent erosion. Trampling or damaging the donor marsh with machinery should be avoided. Dig the plant material or collect cuttings, and place immediately in plastic bags or containers of water to prevent moisture loss. Sprinkle the plants and plant material inside the bags with fresh water to maintain moisture levels if prolonged transport time is required.

126. After the plant material has been brought to the storage or maintenance area, assuming that the site is not ready or the season is not right for immediate planting, the propagules should be treated in the following manner:

a. Immediately pot transplants, sprigs, seedlings, rhizomes, and rootstock in containers with a good all-purpose potting soil or marsh soil brought in from the field for this purpose. "Pots" may take the form of peat pots, conventional plastic containers, or a soil bed set up especially for that purpose. Peat pots are convenient, economical containers for almost all propagules, with the probable exception of large transplants. The chief advantages of these pots are that they can be transferred directly to the field and are biodegradable, thereby lessening transplant shock to the plant material. Their chief disadvantage is that, being made of pressed peat, they become soft with much soaking, and roots of the propagules may grow through the pots before the time for transplanting has arrived. Holding plant propagules in peat pots past 6 months is not recommended.

Soil beds become economical if space is available and plants are to be held for longer periods of time. These can be constructed from 5- by 30-cm lumber and lined with plastic to retain water levels essential to the species in the soil bed. Marsh soil or potting soil can be placed inside the beds, and the propagules planted directly into them. Their chief disadvantage is that plants must be redug from the soil beds before transferring them to the field. If the holding period is less than 6 months, this presents little difficulty; however, if the plants have been retained in the soil bed for longer periods, root systems may have spread and be difficult to protect while removing the plants. Soil beds would be best used for rootstock and rhizomes, as these spread slower than transplants, sprigs, and seedlings in the same period of time.

Regardless of the potting method chosen, it should be remembered that moisture levels for marsh plants are all-important, and water levels must be maintained daily in containers. Care must be taken to assure that each species receives the proper moisture level for its life requirements. A good general rule of thumb is to use undrained pots and to puncture the sides of the containers at about one half their height to allow water to stand in the bottom half of the container. Peat pots are permeable, and therefore do not need puncturing. However, they must be maintained in a water bed that will assure that the plants receive adequate moisture. It is easier to maintain water levels in a soil bed than with any other method.

Unless plants of a larger size are needed by the following spring after plant propagules were obtained in the fall, plants may be stored outside rather than in a greenhouse. They will become dormant with no harm to the plant material as long as their root systems are protected by soil and the required water level. Survival will be best in the areas that have moderate winters.

b. Tubers, depending upon their size and species, are handled differently. They can be maintained, moist but not wet, in cold rooms for a period of time. Large tubers such as saltmarsh bulrush may be best handled by planting in soil beds rather than stored in more expensive refrigerated space. Small tubers such as chufa can be stored in moist but not wet containers in a refrigerator.

c. Dormant cuttings from deciduous species such as willows should be stored wrapped in moist peat moss or buried in sand in a dark, cold room (5° to 10°C) until time to plant. Cuttings then either can be transplanted immediately to the field site and rooted there or can be rooted in a propagation room and planted as transplants.

Herbaceous cuttings should be taken from growing plants and either broadcast directly on the site or rooted in a greenhouse for later transplanting.

127. Plant material must be maintained by an active watering and fertilization program until time to move it to the field site. This maintenance requires experienced personnel. Fertilize each standard size gallon pot with no more than 1 tablespoon of all-purpose fertilizer (13-13-13, NPK) no more often than once each month. Small peat pots require much less fertilizer, and large soil beds may have fertilizer broadcast on them. It is not necessary to fertilize dormant plants. If storage periods are to be of short duration, fertilization could possibly be delayed until after the site is planted.

Pilot propagation study

128. In a marsh development project where there are unknown factors such as seed or sprig collection and planting techniques, effects of animal depredation, rate of plant spread, heavy metal uptake, or lack of experience in similar projects, it is prudent to conduct a pilot study (Barko et al. 1977). A pilot project is particularly advisable if the project is a large and costly one (Figure 25).

129. A pilot study's main purpose is to determine whether or not the selected plant species and propagules will grow under conditions found on the site. The study can be conducted in less than a year, but the test species should be allowed to grow for one full season before conclusions are drawn. Such a project should be of sufficient size that it will accurately reflect future operational difficulties. Each selected species should be tested against all site conditions, and

Figure 25. Pilot propagation study at the Miller Sands site. Several species were tested prior to full scale planting. A pilot study provides a low-cost method of testing project feasibility and determining such variables as best species, elevations, propagule types, need for fertilization, and need for protection

it may be advisable to test more than one propagule type, propagation method, planting time, and plant spacing for each species. The size of the pilot study is limited only by the desired tests, the time available for such testing, and funding. A simple statistical design will permit quantitative evaluation of the study where prediction of degree of success or failure can be made. The success of these plants can generally be evaluated by observation of survival. Test plots established should be evaluated on a regular basis to determine survival and growth, natural plant invasion, erosion, and animal depredation. Same-position photography on a regular basis is also valuable in obtaining a good record of plant success, growth, or die back.

<u>Time of planting</u>

130. Time of planting is very important regardless of the progagule type used. For example, seeds planted before the last frost in the spring may suffer heavy damage, and planting in midsummer may result in heat and drought stress of the seedlings as they sprout. Vegetative

propagules may be planted when the ground is not frozen, and when the day temperatures average less than 20°C. With provisions for local climatic extremes and periods of severe storm or tide activity, propagules are best planted in early to midspring. Along the Gulf and South Atlantic Coasts planting is recommended in all but the summer months. Fall planting, although a horticulturally acceptable practice, is not recommended for marshes as severe loss of propagules may result from erosion of sediments away from the root systems before regrowth begins the following spring. To lessen shock, propagules held in storage inside a nursery or greenhouse should not be planted until temperatures at the field site are at least as warm as the storage area. Propagules held in shady areas should be gradually acclimated to sunny conditions to prevent blistering and death of leaves. Propagules should also be acclimated to the salinity that exists at the site. For example, if saltmeadow cordgrass propagules are dug from a donor marsh of 5-ppt salinity to be planted in a marsh of higher salinity, they could be maintained at 5-ppt until about 2 weeks before planting when they should be moved to a solution of the same salinity as the accepting marsh. If there is a large difference, gradual acclimation is necessary.

Dredged material (soil) bed preparation and treatment

131. Initial dredged material assessment should have revealed certain characteristics of the substrate: texture, salinity, nutrient level, and potentially toxic levels of metals, pesticides, petroleum products, etc. These characteristics were considerations used to select species and propagules and now must be considered in the preparation of the soil bed and any treatments needed for planting such as liming and fertilizing. Actual plot preparation should take place just prior to planting of the site (Figure 26).

132. Grading. Sandy dredged material disposal sites often can be graded to achieve desired slope and elevations (Figure 27). Fine-textured material seldom can be easily modified once placed. See paragraph 96 for further discussion on grading.

133. Liming. Dewatered and potentially acidic material may be

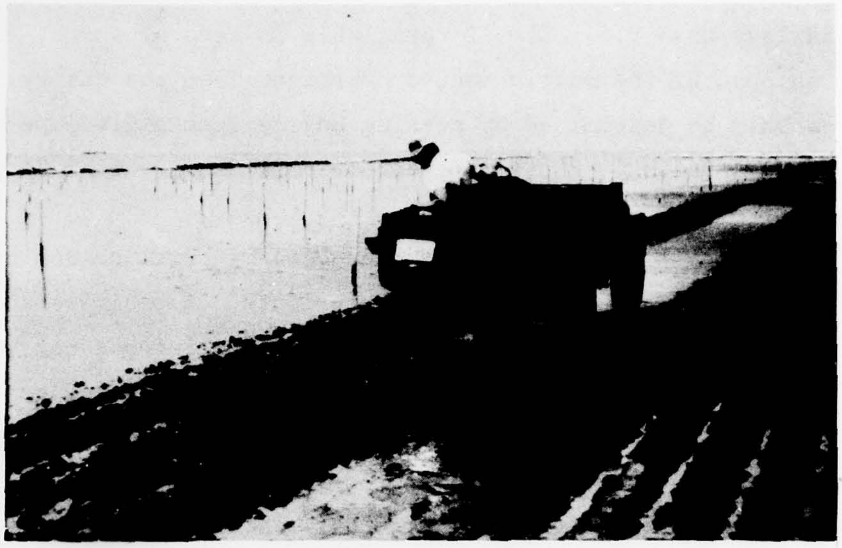


Figure 26. Preparation of sandy dredged material at Bolivar Peninsula prior to planting. Such activities may be applicable only on sandy substrates

Figure 27. Site grading at the Buttermilk Sound site. Sandy substrates can often be easily manipulated to control elevation, drainage, and species diversity

encountered at higher elevations within the marsh development site. Modification of the pH of this dewatered material may be necessary if the pH is less than 5.5. Lime is available in several forms, either bagged, shipped by the metric ton, or straight from the quarry. Rates of lime should be determined by seeking advice from soils experts in the local area (county extension agent or Soil Conservation Service representative).

134. Fertilizer. Fine-textured dredged material seldom needs fertilizer, as it tends to be rich in nutrients. A positive short-term plant response generally can be obtained by fertilizing sandy material although long-term survival of the site may not be affected by fertilizer applications. As a rule of thumb, fertilize only sandy substrates that require rapid and luxuriant cover or that are not undergoing active accumulation of fine material (Figure 28). Fertilizer is best applied to the site before any propagules have been set out or placed adjacent to each vegetative propagule after planting. A good general all-purpose fertilizer such as 13-13-13 (NPK) should be applied at a rate based on soil test analyses. Split applications of fertilizer--an initial application and a midseason application--will result in a more evenly distributed nutrient availability to the plants. This can also be accomplished by using slow-release fertilizers.

Planting the site

135. Seeds. Seeding has the advantage of being inexpensive; however, unless demonstrated to be successful in a pilot study, seeding must be considered an unreliable method of propagation. Seeds are not recommended as propagules for fine-textured dredged material. Seeds on sandy dredged material should be sowed in a well-prepared seed bed that has been plowed and/or disked several centimetres deep. Dry seeds may be broadcast by a hand-whorled seed thrower; all may be sowed in rows and covered with soil by hand. They may also be drilled in rows with a mechanical tractor-operated planter (called a drill-box), which will cover the seeds in the same planting operation. If equipment is available and the site accessible, mechanical seeding is much faster, more efficient, and more economical than hand-seeding. Seeding rates per hectare vary

Figure 28. Fertilizing sandy test plots at the Buttermilk Sound site before planting. Fertilization is seldom necessary on fine-textured material but may be desirable on sandy dredged material

with each species, as does the depth of planting. Seeding rates are dependent on the plant species selected; however, a rule of thumb is that seeds should be sowed generously to allow for the low viability and reduced germination rates often found in wild plants. Depending on seed size and germination rate, this planting rate may vary from 100 to 500 seeds per square metre. A rate of 100 smooth cordgrass seeds per square metre has been recommended by Woodhouse et al. (1974). Small seeded species are usually planted at a depth of 2 cm or less, compared to 2- to 5-cm depths for larger seeded species.

136. Vegetative propagules. A well-prepared seedbed is best for vegetative propagules. It may not be possible to thoroughly prepare a seedbed, especially in fine-textured dredged material. As long as the bed is weed-free, relatively clear of debris, and loose, the preparation is adequate. The most common method of propagation is transplanting by hand (Figure 29). If the site is trafficable, it may be possible to partially mechanize the operation. For example, Salt Pond No. 3 was planted in part by hand from a tractor-drawn sled (Figure 30).

Figure 29. Hand labor is the most common method for transplanting marsh development sites

Figure 30. Planting techniques used at the Salt Pond No. 3 site. A tractor-drawn sled was used to partially mechanize the planting operation

137. If the site is not trafficable, propagules must be planted by hand. On very poorly consolidated dredged material, planting is difficult but possible (Figure 31). Innovations such as planting from small rafts at high tides or using floating walkways to gain access have shown promise. The previously suggested pilot study offers an opportunity to field test innovative techniques or equipment (Kruczynski et al. 1978, Willoughby 1978).

138. Propagules with both roots and top shoots should be planted so that the entire root system is in the dredged material and the top shoots erect after the soil has been firmed around each one (Figure 32). Propagules of only underground material (tubers, rhizomes, rootstocks) should be planted shallowly (less than 5 cm deep).

139. Propagules should be spaced according to the propagule type (see paragraph 107). Large transplants may be spaced on 1.0 to 1.5-m centers. One-metre-center intervals will result in cover in 1 to 2 years; same-year cover can usually only be obtained with large transplants spaced closely together. If very rapid cover is not a consideration and funds are limited, more distant spacing (2 to 3 m) will result in full cover in 2 to 4 years, at a considerable savings in propagules, manpower, and costs. However, an increased erosion rate may result if distant spacing is used. Sprigs and seedlings are usually spaced on 1.0-m centers unless faster cover is desired. In that case, these propagules may be spaced as close as 0.3 m. Underground plant material, because of its slower growth and susceptibility to washing away before establishment, should be planted on 0.5-m centers to ensure an adequate number of propagules to establish the site.

140. Cuttings should be placed upright with two thirds of their length in the soil, and the soil firmed around them. They should only be planted in areas of little or no tidal or current action. Smartweed, glasswort, and other herbaceous cuttings may be broadcast on the site and gently raked into the loose soil so that they are lightly and intermittently covered, then rolled to firm the surface.

Plants for dikes

141. Temporary or permanent dikes must often be erected to contain

Figure 31. Difficulties in hand-planting a fine-textured dredged material site at Apalachicola Bay. Poorly consolidated sites must be hand-planted. Innovations such as floating walkways may be needed at similar sites

Figure 32. Firming dredged material around each transplant to prevent tidal washout

fine-textured dredged material. It may be advantageous to stabilize these with plants to reduce erosion (Figure 33). Representative plants that may be used successfully on dikes in coastal areas are saltmeadow cordgrass, saltgrass, groundsel tree, marsh elder, common reed, seaside goldenrod, beach panic grass, and coastal bermuda grass. These are established using agronomic upland practices set forth in Hunt et al. (1978) and in Coastal Zone Resources Division (1978).

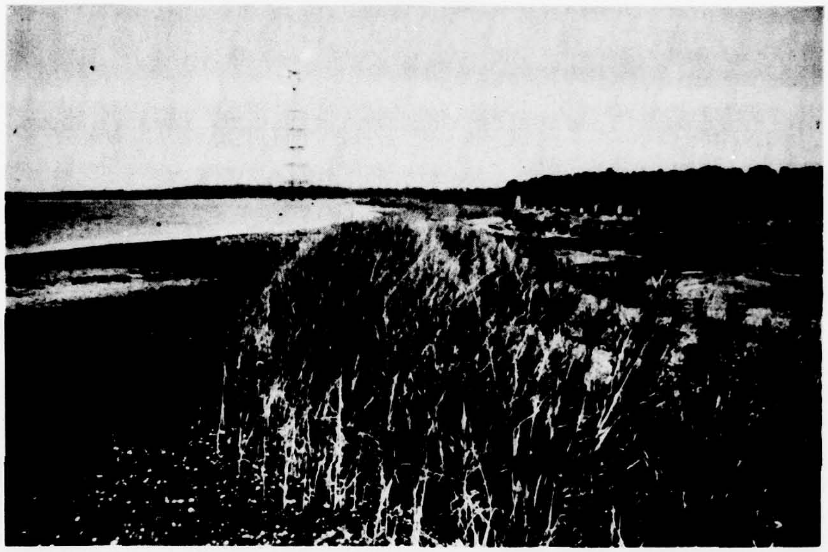


Figure 33. Planted dike for stabilization at the Windmill Point site

142. Dikes in interior and freshwater areas may be planted with species such as tall fescue, reed canary grass, giant reed, common reed, common Bermuda grass, and switchgrass. All these species may be seeded, and most are commercially available.

Natural invasion

143. An alternative to marsh propagation has not previously been presented: natural invasion. The primary disadvantage of natural invasion is that it may take place very slowly. A period of years may be required for propagules to float onto the site by tides or currents or to be carried there by birds and other wildlife. Growth

from that point may also be slow; in the meantime, erosion and aesthetic problems may occur.

144. Another disadvantage to natural colonization is that undesirable plant species may be the invaders, especially if propagules of these species are available from nearby sites. An example of this is the agressive invasion of common reed onto sites left to natural colonization. While it is an excellent soil stabilizer, common reed often crowds out more useful species and is of little benefit to wildlife. Prediction of invaders may be unreliable since there are a number of candidate species.

145. Natural colonization of marsh sites is feasible and desirable under certain circumstances. In those cases where abundant, desirable propagule sources are near, when rapid cover is not necessary, and when environmental conditions are not harsh, natural colonization is an inexpensive, simple means of establishing vegetation. An example of these conditions was provided at the Windmill Point site, which became vegetated 6 months after construction (Figure 34).

Figure 34. Natural colonization at the Windmill Point site. A variety of fresh marsh plant species (pickerelweed, arrow arum, smartweeds, and broadleafed arrowhead) invaded the site

Postpropagation Maintenance and Monitoring

146. There are two major considerations in postpropagation phases of any project: to maintain or not to maintain the site. Nonmaintenance has advantages of allowing natural succession to take place once the initial establishment is assured and involves no additional expenditures. Disadvantages that could result from lack of maintenance are:

- a. Invasion by unwanted and undesirable plant species resulting in a major alteration in the site and its intended purpose.
- b. Colonization by undesirable wildlife species that may exclude species for which the site was originally intended.
- c. Major changes in topography such as breaches of dikes, severe storm damage, and erosion gullies. These should be repaired to prevent unwanted alteration of the site.

147. There are several reasons for monitoring a site and continuing site maintenance. These are:

- a. To determine the need for further soil treatment, e.g., fertilizer application.
- b. To arrange for replacement plantings or additional plantings.
- c. To determine the need for control measures for invertebrate and vertebrate pests, plant diseases, or invading plant species.
- d. To remove accumulations of litter or debris that might smother the plantings.

148. An additional reason for continued monitoring of the site is the systematic collection of data that may be used to determine the feasibility of marsh development at other sites. Technology concerning marsh establishment is still in beginning stages and basic quantitative data on the success or failure of various techniques or methodologies will substantially advance the state of the art.

149. Techniques for monitoring a site should be tailored to the site itself and the monitoring objective. Either ground observations or remote sensing or a combination of both may be appropriate. See paragraph 14 for further discussion of ground sampling. Reimold et al.

(1978) describe use of remote sensing on smooth cordgrass marshes. Two additional sources of information are National Academy of Sciences (1970) and the International Symposia on Remote Sensing of the Environment sponsored annually by the University of Michigan.

Potential Problems

Project timing

150. Dredging and biological calendars frequently do not match. There are two key items regarding biological scheduling:

- a. Predictable lead time is necessary to prepare some propagule types.
- b. Planting is usually best in the spring.

Transplants grown in a greenhouse cannot be held beyond a certain point without greatly increasing costs and weakening the propagules. Similarly, seeds must be collected when they mature in the field and often will not remain viable for extended periods of time. Dredging schedules are often variable, particularly so when new disposal techniques are being employed. In most situations the dredging schedule will predominate; therefore, it is best to not initiate all planting preparations until dredging times are assured. In most situations a delay of 4 to 6 months between completion of dredging and propagation will be acceptable. If this is not acceptable, the dredging schedule should be adjusted if possible. Late summer dredging will usually result in a site being ready for propagation in the spring of the following year. It will often not be possible to dredge and plant in the same calendar year as both procedures are subject to time constraints and delays.

Contaminant uptake by plants

151. Metals and chlorinated hydrocarbon compounds commonly associated with industrial, agricultural, and urban areas may be transferred to marsh plants from the air, water, or marsh substrate. When contaminated dredged material is used for marsh development, the potential for contaminant transfer should be considered. Studies by Gambrell et al. (1977), Khalid et al. (1977), Lee et al. (1976 and 1978), and Lunz (1978) indicated that contaminants are transferred from marsh soils to plants

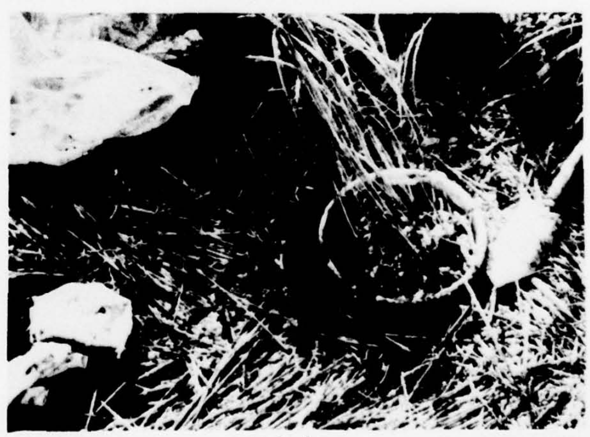
under conditions that are influenced by the characteristics of the contaminant, the plant species, and physical and chemical soil properties.

152. Plant species differ in their ability to select or exclude certain chemicals for uptake or internal transport. Most of what is known about plant selectivity is the result of agricultural studies of crop plants in upland environments. At this time, information about marsh plant contaminant uptake is not adequate to describe the importance of the plant species relative to the other environmental conditions affecting contaminant transfer. The nature of the contaminant itself is important. For example, lead is usually limited to underground plant parts and is not readily transported to aboveground plant parts; mercury is readily transported through the plant to aboveground plant parts. Soil properties are important because they influence the physical and chemical form of a contaminant. Soil organic content, cation exchange capacity, pH, and oxidation-reduction potential (Eh) affect the maintenance of a contaminant in a more or less soluble or insoluble condition. In most instances, a contaminant must be in solution before it can be taken up by a plant. Because a contaminant is soluble in a soil-water system does not mean it will always be taken up by plants, but there is a relationship between solubility or ease of solubility and potential uptake. If environmental conditions maintain a contaminant in a solid phase, that contaminant cannot be transferred to plants. If conditions allow the contaminant to enter a solution or gas phase, the potential for plant uptake is increased.

153. Because of the complex and poorly understood interactions between marsh plants and soils affecting contaminant transfer, and the evidence that transfer can occur, under certain conditions, an empirical field test procedure is recommended. Preliminary specifications for a relatively inexpensive field procedure called a bioassay experiment test (Figure 35) are presented in Wolf et al. (1978), although certain refinements are necessary before this method is ready for general field application. A general discussion of the use of contaminated dredged material in marsh development with management recommendations is presented in Gambrell et al. (1978).

(a)

(b)



(c)

Figure 35. Field bioassay experiment test. In this test for heavy metal uptake by marsh plants, a series of experimental units, (a) are filled with the dredged material in question, (b) placed in a natural marsh, and (c) planted. After a period of growth the plants are harvested and new growth is analyzed for contaminant uptake

Invasion of
nonpreferred plant species

154. In brackish or freshwater marshes, invasion of unwanted plant species can occur readily if propagules of those species are already present nearby. The most frequent invader in the east and Gulf Coast areas with the exception of south Florida and Texas is common reed; in freshwater areas, broadleaf cattails may create dense stands. Although these two species have value for soil stabilization and wildlife use, they may grow in too dense a stand for maximum wildlife diversity and require control. If the final elevation of a salt marsh substrate is higher than planned and relatively free of tidal inundation, common reed and more upland species may invade. If it is high but tidal inundation still occurs, a high marsh may result when a low marsh was planned.

Pests and diseases

155. Wildlife and feral animals of domestic breeds can destroy newly planted vegetation or retard succession by grazing or trampling. Grazing pressure varies among regions and situations. For example, Canada geese destroyed many plants at the Windmill Point marsh site (Lunz et al. 1978), but goose depredation was minimal at the Miller Sands site (Crawford and Edwards 1978). Potential control methods include fencing the site to exclude pests, trapping and removing pests, locating the site at a sufficient distance from pest sources, and planning the project so as not to coincide with a known pest problem. Infestations of harmful pests such as chewing insects and snails will cause occasional problems and should be dealt with, if necessary, as they occur. Pest prevention techniques should be tailored to the site. Garbisch (1977) has additional suggestions on pest control.

156. While plant diseases do occur among marsh species, healthy stands will generally not become heavily infected. Only in cases of severe infections should control measures be undertaken. Since the water that flows in and out of a marsh serves as a source of reinfection, cutting and burning or spraying techniques such as those used for control on upland sites (Hunt et al. 1978) may have no long-lasting effect on the marsh site. However, these techniques may serve to temporarily

control a disease until healthy plants can reestablish themselves on the marsh.

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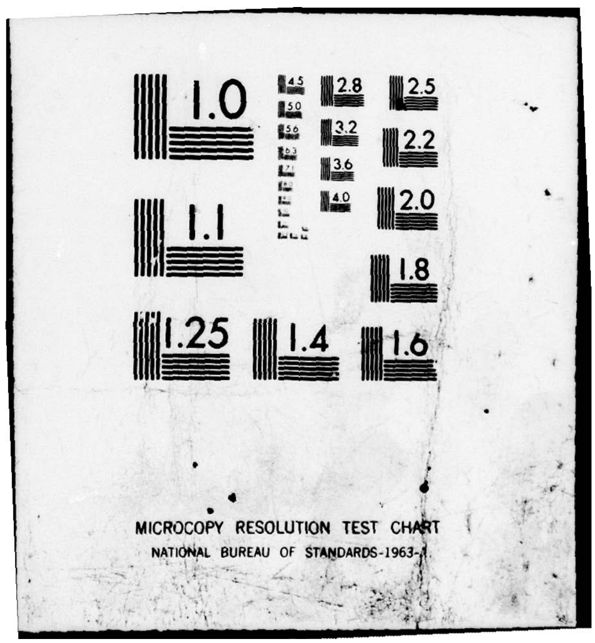
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PART V: COSTS

157. The costs of planning, constructing, and propagating a site are based on many considerations, which are discussed in Parts II, III, and IV of this report. Costs of the site are determined from decisions regarding these considerations and the project goals and are usually very site-specific. Each of the six DMRP marsh development sites varied considerably in cost, reflecting the various specificities and research demands encountered.

Planning

158. Planning costs involve site selection, site characterization, engineering and planting design, and coordination. In a comparison of two DMRP field sites, planning and engineering design costs were $45,000 ($5,600/ha) at Bolivar Peninsula and $35,000 ($4,400/ha) at Windmill Point. Both of these sites are approximately 8 ha in size. The planning and engineering costs of these projects were increased by detailed research aspects and difficult site problems. More conventional marsh development sites should have substantially lower planning costs.

Construction

159. Construction costs vary greatly and are influenced by such variables as access to the site, distance between the dredging and disposal sites, dredged material and foundation characteristics, energy regimes, cost of protective structures, availability of equipment, and local labor rates. Most of the construction costs encountered in marsh development are associated with conventional methods of confined dredged material disposal. Special costs associated with habitat development may include fencing or elevation adjustments. The variable costs of protective structures are presented in Table 8. Construction costs exclusive of actual dredging were $288,000 ($36,000/ha) at Bolivar

Peninsula and $167,500 ($21,000/ha) at Windmill Point. These totals include dike construction and maintenance, postconstruction grading and elevational changes, and other site preparation measures. The reason for the substantial cost difference is primarily the result of use of a more expensive protective structure (fabric bags) at Bolivar Peninsula. A temporary sand dike was employed at Windmill Point.

Propagation

160. Dollar figures and estimated times for planting have been given by several investigators (Dodd and Webb 1975, Garbisch et al. 1975, Knutson 1977, Morris et al. 1978, Ternyik 1978, Woodhouse et al. 1972, and Zarudsky 1975). Because of regional differences, plant species selected, collection and planting techniques, skill of personnel, and other factors, these costs varied greatly. The transplant figures presented are expressed in cost per hectare, assuming that plants were established on 1-m centers (10,000 plants/ha). Depending upon project objectives, cover could be obtained by more or less intensive plantings. A 0.5-m spacing would require 40,000 plants/ha; 2-m spacing would require 2,500 plants/ha. It is advisable to plan to obtain more propagules than the estimate needed for contingency in case of the loss of some propagules, death of some plantings, or the site being constructed at a different elevation than planned.

161. Woodhouse et al. (1972) found that collecting and transplanting smooth cordgrass by hand on 1-m centers required 134 man-hours/ha on sandy dredged material in North Carolina. He also experimented with smooth cordgrass seeds and found harvest more efficient by machine than by hand. In general he and Garbisch et al. (1975) found that seeds are an economical propagule type but have the least successful establishment rate.

162. Dodd and Webb (1975) compiled data from their research on the Texas coast, showing man-hours/1000 plants required to hand dig, separate, and transplant various propagule types of 11 marsh species (Table 9). Variations in man-hours resulted when difficulties were

encountered in separating clumps or digging dense, stout root systems. These figures range from 11.3 to 29.3 man-hours/1000 plants (113 to 293 man-hours/ha).

163. Planting of the Miller Sands marsh site in the Columbia River, which was composed of sandy dredged material, is described in Ternyik (1978). Table 10 shows transplant digging and planting man-hours and costs, and Table 11 shows seed collection man-hours and costs. Ternyik encountered only minimal difficulty in obtaining and separating material. Tufted hairgrass transplants required 87 man-hours/ha for digging and planting, the least manpower required for those species planted at Miller Sands. Low manpower efforts at this site overall are probably reflections of a professional nursery work force, highly skilled in transplanting techniques.

164. Marsh propagation costs will be extremely site-specific and will reflect such factors as logistics, man-hour costs and efficiency, planting design, and the texture of the substrate. The data presented here are developed from sites that could support conventional equipment. Poorly consolidated, fine-textured dredged material will require more man-hours to propagate due to trafficability problems.

165. As a general rule, man-hour efforts should range from:

a. 100 to 200 man-hours/ha for transplants and sprigs.

b. 100 to 150 man-hours/ha for rhizomes, tubers, and rootstocks.

c. 10 tc 40 man-hours/ha for seeds.

The above figures are for labor only and may be used to calculate costs of the propagation effort based on current labor wages.

166. Equipment and supply costs are indicated below, and are estimates in 1978 prices.

a. Bulldozer for elevational adjustments and transplant bed preparation--$30 to 75/hr.

b. Tractor and disk for seedbed preparation (coarse-grained material only)--$10 to 35/ha per trip over the site, $20 to 70/ha for double cutting.

c. Fertilizer. All-purpose 13-13-13 (NPK)--$13.20/100 kg.

d. Lime. Costs of lime and spreading--$10 to 15/metric ton.

e. Plants from commercial source. Marsh transplants may be obtained from a few commercial firms at costs ranging from $0.14 to $0.75 per plant, and seeds of some species may be available. Consult a local source for these propagules. A list of commercial and Government sources of upland propagules is given in Hunt et al. (1978); many of these firms will supply limited marsh propagules as well. DMRP commercial sources included Wave Beach Grass Nursery, Florence, Oregon; Environmental Concern, Inc., St. Michael's, Maryland; and San Francisco Bay Marine Research Center, San Bruno, California.

167. In estimating costs for any marsh habitat development site, the most important thing for the planner to remember is that all sites are different, and each site must be evaluated on an individual basis.

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Table 1

Addresses of U. S. Fish and Wildlife Service Regional Endangered Species Coordinators, by Region and State

Region	States Included	Coordinator's Address
Alaska Area	Alaska	Endangered Species Coordinator U. S. Fish and Wildlife Service 813 D Street Anchorage, AK 99501
1	Washington, Oregon, Idaho, California, Nevada, Hawaii	Endangered Species Coordinator U. S. Fish and Wildlife Service Lloyd 500 Building 500 N.E. Multnomah Street Portland, OR 97232
2	Arizona, New Mexico, Texas, Oklahoma	Endangered Species Coordinator U. S. Fish and Wildlife Service Federal Building, U. S. Post Office and Courthouse 500 Gold Avenue, S.W. P. O. Box 1306 Albuquerque, NM 87103
3	Minnesota, Wisconsin, Michigan, Illinois, Indiana, Ohio	Endangered Species Coordinator U. S. Fish and Wildlife Service Federal Building, Fort Snelling Twin Cities, MN 55111
4	Kentucky, Arkansas, Tennessee, North Carolina, Louisiana, Mississippi, Alabama, Georgia, South Carolina, Florida, Puerto Rico and Virgin Islands	Endangered Species Coordinator U. S. Fish and Wildlife Service 17 Executive Park Drive, N.E. P. O. Box 95067 Atlanta, GA 30329
5	Maine, New Hampshire, Vermont, Massashusetts, Connecticut, Rhode Island, New York, Pennsylvania, New Jersey, Delaware, Maryland, West Virginia, Virginia	Endangered Species Coordinator U. S. Fish and Wildlife Service One Gateway Center Newton Corners, MA 02158
6	Montana, North Dakota, South Dakota, Wyoming, Nebraska, Iowa, Utah, Colorado, Kansas, Missouri	Endangered Species Coordinator U. S. Fish and Wildlife Service 10597 W. Sixth Avenue P. O. Box 25486 Denver Federal Center Denver, CO 80225

Table 2

Laboratory Testing of Fine-Grained Cohesive Soils*

Test	Purpose	Scope of Testing
Visual classification	Visually classify the soil in accordance with the Unified Soil Classification System	All samples
Water content	Determine the water content of the soil in order to better define soil profiles, variation with depth, and behavioral characteristics	All samples
Atterberg limits	Foundation soils: for classification, comparison with natural water contents, or correlation with shear or consolidation parameters Borrow soils: for classification, comparison with natural water contents, or correlations with optimum water content and maximum dry densities	Representative samples of foundation and borrow soils. Sufficient samples should be tested to develop a good profile with depth
Compaction	Establish maximum dry density and optimum water content	Representative samples of all borrow soils for compacted or semicompacted dikes: Compacted - perform standard 25-blow test Semicompacted - perform 15-blow test
Consolidation	Determine parameters necessary to estimate settlement of dike and/or foundation and time-rate of settlement. Also, to determine whether soils are normally consolidated and to aid in estimating strength gain with time	Representative samples of compacted borrow where consolidation of dike embankment itself is expected to be significant Representative samples of foundation soils where such soils are anticipated to be compressible Samples of fine-grained adjacent and/or underlying materials at structure locations
Permeability	Estimate the perviousness of borrow and/or foundation soils and so calculate seepage losses and time-rate of settlement	Generally not required for fine-grained cohesive soils as such soils can be assumed to be essentially impervious in seepage analyses. Can be computed from consolidation tests
Shear strength	Provide information for retention structure design Pocket penetrometer, miniature vane, unconfined compression, and triaxial tests to determine unconsolidated-undrained strengths and consolidated-undrained strengths. Direct shear tests to determine consolidated-drained strengths as appropriate	Pocket penetrometer and miniature vane (Torvane for rough estimates) Unconfined compression tests on saturated foundation clays without joints, fissures, or slickensides Appropriate triaxial and direct shear tests on representative samples of both foundation and compacted borrow soils for dikes

* Modified from Hammer and Blackburn (1977).

Table 3

Laboratory Testing of Coarse-Grained Noncohesive Soils*

Test	Purpose	Scope of Testing
Visual classification	Visually classify the soil in accordance with the Unified Soil Classification System	All samples
Gradation	Determine grain-size distribution for classification and correlation with permeability and/or shear strength parameters	Representative samples of foundation and borrow materials for dikes
Relative density or compaction	Determine minimum-maximum density values or maximum density and optimum water content values	Representative samples of all borrow materials for dikes. Use the test which gives greatest values of maximum density
Consolidation	Provide parameters necessary for settlement analysis	Not generally required, as pervious soils consolidate rapidly under load and postconstruction magnitude is usually significant
Permeability	Provide parameters necessary for seepage analysis	Not usually performed, as correlations with grain size are normally of sufficient accuracy
Shear strength	Provide parameters necessary for stability analysis	Representative samples of compacted borrow and foundation soils. Consolidated drained strengths from direct shear and triaxial tests are appropriate for free-draining pervious soils Conservative shear strength values can usually be assumed based on test results from similar soils

* Modified from Hammer and Blackburn (1977).

Table 4

Protective and Retention Structures and Their Applicability

Structure	Function	Maximum Feasible Height	Special Foundation Requirements	Erosion Resistance	Duration	Relative Cost	Remarks
Sand dike (hydraulically placed)	Protection and retention	Foundation dependent	None	Depends on material used	Long	Low	Build from coarsest material available
Sand dike (end dumped)	Protection and retention	Foundation dependent	None	Depends on material used	Long	Low	Land borrow may be available
Retaining wall (cantilevered)	Protection and retention	4.5 m	Firm bottom	Good	Long	Moderate to low	Wall usually constructed with sheet-pile; reclamation of piling recommended
Retaining wall (anchored)	Protection and retention	12.0 m	Select backfill	Good	Long	Moderate to high	Construction usually performed by floating plant; adequate operating depth required
Coffer dam	Protection and retention	6.0 m	None	Good	Long	High	Limited applicability in habitat development
Gabion	Protection and retention	3.0 m	None	Susceptible to scour	Intermediate	Moderate	Requires availability of small rock
Fabric bags	Protection and retention	varies	None	Good	Long if concrete filled, short if sand filled	Low	Susceptible to vandalism; degrades in 2-3 years
Revetment	Protection	--	None	Good	Long	Low to high	Used in conjunction with dikes
Offshore sill	Protection	--	None	Moderate	Long	Low to medium	Causes waves to break before reaching substrate
Floating breakwater	Protection	--	None	--	Intermediate	Low	Reduces wave heights
Groin	Protection	--	None	Good	Long	Low to high	Causes waves to break before reaching substrate

Table 5

Construction Equipment Available for Habitat Development

Operation	Equipment Used: On Land	Equipment Used: In Shallow Water	Equipment Used: Off Shore
Clearing foundation	Bulldozer Dragline	Dragline on timbermats	Floating dragline
Obtaining material	Bulldozer Dragline Truck transport from borrow area	Clamshell Dragline on pontoons Dragline on timbermats Hydraulic dredge and pipeline Truck transport from borrow area	Barged dragline Clamshell Hydraulic dredge and pipeline Barged transport from borrow area
Placing material	Dragline Bulldozer Hydraulic fill* End-dumping from trucks	Dragline on pontoons End-dumping from trucks Hydraulic fill	Bottom-dump scows Barge with conveyor Hydraulic fill* Barged dragline
Shaping and compacting**	Bulldozer Scrapers Haul traffic	Bulldozer Haul traffic Dragline	Bulldozer Dragline
Placing riprap	——	Clamshell	Barged clamshell

* Various hydraulic fill procedures have been used, including: bleeder pipe (on land, shallow water); whooping crane (on land); spillbarge (on water)--used virgin clay source; floating swing discharge line.

** Compaction normally carried out on 0.3-m added layers of fill on emergent portions of dike.

Table 6

Selected Marsh Species and Their General Growth Requirements and Characteristics

Species	Region* SA	NA	PF	GC	WC	I	Soil Conditions: pH Acid	Neutral	Alkaline	Salinity Fresh	Brackish	Saline	Texture Fine	Coarse	Marsh Moisture Conditions: Standing Water	Tidal Low	Tidal High	Interior Low Fresh	Interior High Fresh	Interior Brackish	Wildlife Value Food	Cover	Nesting/ Breeding	Morphology Perennial	Annual	Potential Nuisance	Soil Stabilizer
Alkali bulrush (*Scirpus paludosus*)		✓**			✓	✓		✓	✓	✓	✓		✓	✓			✓		✓	✓	✓	✓		✓			✓
Arrow arum (*Peltandra virginica*)	✓	✓	✓	✓		✓	✓	✓	✓	✓			✓						✓		✓	✓	✓	✓		✓	✓
Beak rush (*Rynchospora tracyi*)	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓			✓		✓		✓	✓		✓			✓
Beggar's ticks (*Bidens* spp.)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓		✓		✓	✓		✓	✓	✓	✓
Big cordgrass (*Spartina cynosuroides*)	✓	✓	✓	✓			✓	✓	✓	✓	✓		✓	✓		✓	✓				✓	✓	✓	✓		✓	✓
Bigelow's glasswort (*Salicornia bigelovii*)	✓	✓	✓	✓			✓	✓	✓		✓	✓	✓	✓		✓	✓					✓		✓			✓
Black mangrove (*Avicennia nitida*)			✓	✓			✓	✓	✓		✓	✓	✓	✓		✓						✓	✓	✓			✓
Black needlerush (*Juncus roemerianus*)	✓		✓	✓			✓	✓	✓	✓	✓		✓	✓			✓					✓		✓		✓	✓
Bladderworts (*Utricularia* spp.)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓			✓			✓	✓		✓		✓	
Broadleaf arrowhead (*Sagittaria latifolia*)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓		✓			✓	✓		✓	✓	✓	✓			✓
Broadleaf cattail (*Typha latifolia*)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓			✓			✓	✓	✓	✓		✓	✓
Bulrushes (*Scirpus* spp.)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Burreed (*Sparganium americanum*)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓					✓		✓	✓		✓			✓
Buttercups (*Ranunculus* spp.)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓			✓				✓		✓		✓	
Buttonbush (*Cephalanthus occidentalis*)	✓		✓	✓		✓	✓	✓	✓	✓			✓	✓	✓			✓	✓		✓	✓	✓	✓			✓
Chufa (*Cyperus esculentus*)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓						✓		✓	✓		✓			✓
Common reed (*Phragmites australis*)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓		✓	✓		✓	✓	✓		✓	✓
Common threesquare (*Scirpus americanus*)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓			✓	✓	✓	✓	✓			✓
Delta duckpotato (*Sagittaria platyphylla*)			✓	✓			✓	✓	✓	✓			✓	✓				✓	✓		✓	✓		✓			✓
Docks (*Rumex* spp.)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓					✓		✓	✓		✓		✓	✓
Dotted smartweed (*Polygonum punctatum*)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓					✓		✓	✓		✓	✓		✓
Duckpotato (*Sagittaria cuneata*)		✓			✓	✓	✓	✓	✓	✓			✓					✓	✓		✓	✓		✓			✓
Duckweeds (*Lemna* spp.)	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓		✓						✓	✓		✓		✓	
Eel grass (*Zostera marina*)	✓	✓			✓		✓	✓	✓		✓	✓	✓	✓	✓	✓					✓	✓		✓			✓

(Continued)

* SA = south Atlantic; NA = north Atlantic; PF = peninsula Florida; GC = gulf coasts; WC = west coast; I = interior.
** ✓ indicates positive occurrence tolerance, value, or characteristic. No ✓ indicates negative or doubtful information.

Table 6 (Continued)

	Region						Soil Conditions								Marsh Moisture Conditions						Wildlife Value			Morphology		Potential	Soil
							pH			Salinity			Texture		Stand-ing	Tidal		Interior									Stabili-
Species	SA	NA	PF	GC	WC	I	Acid	Neutral	Alkaline	Fresh	Brackish	Saline	Fine	Coarse	Water	Low	High	Low Fresh	High Fresh	Brackish	Food	Cover	Nesting/ Breeding	Perennial	Annual	Nuisance	zer
European glasswort (Salicornia europaea)	✓	✓	✓	✓			✓	✓	✓			✓	✓	✓		✓						✓	✓	✓			✓
Fimbristylis (Fimbristylis castanea)	✓	✓	✓	✓			✓	✓	✓	✓	✓		✓	✓			✓		✓	✓	✓	✓		✓			✓
Foxtail grasses (Setaria spp.)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓					✓		✓	✓	✓	✓	✓	✓	✓
Frankenia (Frankenia grandifolia)					✓		✓	✓	✓		✓		✓	✓		✓	✓					✓		✓			
Frog bit (Limnobium spongia)	✓	✓	✓	✓		✓	✓	✓	✓	✓			✓	✓				✓	✓		✓	✓		✓	✓		✓
Giant reed (Arundo donax)	✓		✓	✓		✓	✓	✓	✓	✓			✓	✓				✓	✓		✓	✓	✓	✓			✓
Groundsel tree (Baccharis halimifolia)	✓	✓	✓	✓			✓	✓	✓	✓	✓		✓	✓			✓					✓	✓	✓			✓
Hardstem bubrush (Scirpus acutus)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓	✓	✓	✓	✓	✓		✓			✓
Horned pondweed (Zannichellia palustris	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓		✓	✓	✓		✓			✓
Horsetails (Equisetum spp.)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓	✓	✓	✓		✓	✓	✓		✓	✓
Japanese millet (Echinochloa crus-galli	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓					✓		✓	✓			✓		✓
Ladysthumb (Polygonum persicaria)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓					✓			✓		✓			✓
Lizard's tail (Saururus cernuus)	✓	✓	✓	✓		✓	✓	✓		✓			✓					✓	✓		✓	✓		✓			✓
Lobelia (Lobelia dortmanna)		✓			✓	✓	✓	✓	✓	✓			✓	✓					✓			✓					
Lotus (Nelumbo lutea)	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓	✓	✓			✓			✓	✓		✓		✓	✓
Lyngbye's sedge (Carex lyngbyei)					✓		✓	✓		✓			✓	✓					✓		✓	✓		✓			✓
Manna grass (Glyceria acutiflora)	✓	✓		✓		✓	✓	✓	✓	✓			✓	✓	✓			✓			✓	✓	✓	✓			✓
Manna grass (Glyceria fluitans)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓				✓	✓		✓	✓		✓			✓
Marsh elder (Iva frutescens)	✓	✓	✓	✓			✓	✓	✓	✓	✓		✓	✓			✓					✓	✓	✓			✓
Marsh hibiscus (Hibiscus moscheutos)	✓		✓	✓			✓	✓		✓			✓	✓				✓	✓		✓	✓	✓	✓			✓
Marsh pepper (Polygonum hydropiper)	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓	✓				✓	✓		✓	✓		✓	✓	✓	✓
Marsh smartweed (Polygonum hydropiperoides)	✓	✓	✓	✓		✓	✓	✓		✓			✓	✓				✓	✓		✓	✓		✓		✓	✓
Mud plantain (Heteranthera reniformis)	✓	✓	✓	✓		✓	✓	✓		✓			✓						✓			✓		✓			✓
Nodding smartweed (Polygonum lapathifolium)	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓	✓				✓	✓		✓	✓	✓	✓		✓	✓
Nutsedges (Cyperus spp.)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓				✓	✓		✓	✓	✓	✓		✓	✓

(Continued)

Table 6 (Continued)

Species	Region						Soil Conditions								Marsh Moisture Conditions						Wildlife Value			Morphology		Potential Nuisance	Soil Stabilizer
							pH			Salinity			Texture		Standing Water	Tidal		Interior									
	SA	NA	PP	GC	WC	I	Acid	Neutral	Alkaline	Fresh	Brackish	Saline	Fine	Coarse		Low	High	Low Fresh	High Fresh	Brackish	Food	Cover	Nesting/ Breeding	Perennial	Annual		
Olney's threesquare (Scirpus olneyi)	✓			✓	✓		✓	✓		✓	✓		✓				✓			✓	✓	✓		✓			✓
Orache (Atriplex patula)	✓	✓		✓			✓	✓	✓	✓	✓			✓			✓			✓		✓		✓			✓
Pacific cordgrass (Spartina foliosa)					✓		✓	✓			✓	✓	✓	✓		✓					✓	✓		✓			✓
Pacific glasswort (Salicornia pacifica)					✓		✓	✓	✓		✓	✓	✓	✓		✓	✓					✓		✓			✓
Pacific sedge (Carex obnupta)					✓		✓	✓		✓	✓		✓	✓			✓				✓	✓	✓	✓			✓
Panic grasses (Panicum spp.)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
Paspalum grasses (Paspalum spp.) .	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓		✓	✓	✓	✓	✓	✓	✓		✓
Pennsylvania smartweed (Polygonum pensylvanicum)	✓	✓	✓	✓		✓	✓	✓		✓			✓	✓				✓	✓		✓	✓		✓			✓
Pennyworts (Hydrocotyle spp.)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓		✓	✓	✓	✓		✓	✓	✓		✓	✓
Pickerelweed (Pontederia cordata)	✓	✓	✓	✓		✓	✓	✓		✓			✓					✓			✓	✓	✓	✓		✓	✓
Pondweeds (Potomogeton spp.)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓						✓	✓		✓		✓	
Prairie cordgrass (Spartina pectinata)	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓		✓	✓			✓	✓	✓	✓	✓			✓
Red mangrove (Rhizophora mangle)			✓				✓	✓	✓			✓	✓	✓	✓	✓						✓	✓	✓			✓
Reed canary grass (Phalaris arundinacea)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓					✓		✓	✓	✓	✓			✓
Reed grass (Calamagrostis canadensis)	✓				✓	✓	✓	✓	✓	✓			✓	✓					✓		✓	✓	✓	✓			✓
Reed manna grass (Glyceria grandis)	✓	✓		✓	✓	✓	✓	✓	✓	✓			✓	✓					✓		✓	✓	✓	✓			✓
Rice cutgrass (Leersia oryzoides)	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓	✓	✓			✓			✓	✓		✓			✓
River bulrush (Scirpus fluviatilis)		✓			✓	✓	✓	✓	✓	✓			✓	✓	✓			✓	✓		✓	✓	✓	✓			✓
Rushes (Juncus spp.)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓		✓	✓	✓	✓	✓	✓		✓	✓
Saltgrass (Distichlis spicata)	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓		✓	✓				✓	✓	✓	✓			✓
Saltmarsh aster (Aster tenuifolius	✓	✓	✓	✓			✓	✓	✓		✓		✓	✓			✓					✓		✓			✓
Saltmarsh bulrush (Scirpus robustus)	✓	✓	✓	✓			✓	✓	✓		✓	✓	✓				✓			✓	✓	✓	✓	✓			✓
Saltmarsh cattail (Typha angustifolia	✓	✓	✓	✓			✓	✓		✓	✓		✓	✓			✓		✓	✓		✓	✓	✓			✓
Saltmarsh jaumea (Jaumea carnosa)					✓		✓	✓					✓	✓			✓					✓		✓			✓
Saltmeadow cordgrass (Spartina patens)	✓	✓	✓	✓			✓	✓	✓		✓		✓	✓			✓				✓	✓	✓	✓			✓

(Continued)

(Sheet 3 of 5)

Table 6 (Continued)

Species	Region						Soil Conditions								Marsh Moisture Conditions						Wildlife Value			Morphology		Potential Nuisance	Soil Stabilizer
							pH			Salinity			Texture		Standing Water	Tidal		Interior									
	SA	NA	PF	GC	NC	I	Acid	Neutral	Alkaline	Fresh	Brackish	Saline	Fine	Coarse		Low	High	Low Fresh	High Fresh	Brackish	Food	Cover	Nesting/ Breeding	Perennial	Annual		
Saw grass (Cladium jamaicense)			✓				✓	✓	✓	✓			✓	✓	✓			✓	✓		✓	✓	✓	✓			✓
Sea lavender (Limonium carolinianum)	✓	✓	✓	✓			✓	✓	✓	✓	✓		✓	✓			✓					✓		✓			✓
Sea lavender (Limonium vulgare)	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓	✓			✓					✓	✓	✓			✓
Sea ox-eye (Borrichia frutescens)	✓		✓	✓			✓	✓	✓			✓	✓	✓		✓	✓					✓	✓	✓			✓
Sea purslane (Sesuvium portulacastrum)	✓	✓	✓	✓			✓	✓	✓	✓	✓		✓	✓			✓					✓	✓	✓			✓
Seaside arrowgrass (Triglochin maritima)		✓			✓			✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓		✓			✓
Sedges (Carex spp.)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓	✓	✓	✓	✓	✓	✓	✓			✓
Shoal grass (Halodule wrightii)	✓		✓	✓				✓	✓			✓	✓	✓	✓						✓	✓		✓			✓
Slough grass (Beckmannia syzigachne)		✓		✓	✓		✓	✓		✓			✓	✓					✓			✓		✓			✓
Slough sedge (Carex obnupta)		✓			✓	✓	✓	✓		✓			✓	✓				✓	✓		✓	✓	✓	✓			✓
Smartweeds (Polygonum spp.)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓			✓	✓		✓	✓	✓	✓		✓	✓
Smooth cordgrass (Spartina alterniflora)	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓		✓					✓	✓	✓	✓			✓
Soft rush (Juncus effusus)	✓		✓	✓		✓	✓	✓			✓		✓						✓		✓	✓	✓	✓		✓	✓
Softstem bulrush (Scirpus validus)	✓	✓	✓	✓	✓	✓	✓	✓			✓		✓					✓	✓		✓	✓	✓	✓			✓
Southern bulrush (Scirpus californicus)	✓		✓	✓	✓	✓	✓	✓			✓		✓	✓				✓	✓		✓	✓	✓	✓			✓
Southern smartweed (Polygonum densiflorum)	✓		✓	✓		✓	✓	✓			✓		✓	✓				✓	✓		✓	✓		✓			✓
Southern cutgrass (Zizaniopsis miliacea)	✓		✓	✓		✓	✓	✓	✓		✓		✓					✓			✓	✓	✓	✓			✓
Spatterdock (Nuphar luteum)	✓	✓	✓	✓	✓	✓	✓	✓			✓		✓					✓	✓		✓	✓		✓			✓
Spikerushes (Eleocharis spp.)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓			✓	✓	✓	✓	✓	✓		✓			✓
Spirodella (Spirodella polyrhiza)	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓		✓						✓	✓		✓		✓	✓
Sprangletop (Leptochloa fascicularis)	✓			✓			✓	✓		✓			✓	✓					✓		✓	✓	✓	✓			✓
Sweet flag (Acorus calamus)	✓					✓	✓	✓		✓			✓						✓			✓		✓			✓
Tufted hairgrass (Deschampsia caespitosa)		✓			✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓			✓	✓	✓			✓
Turtle grass (Thalassia testudinum)	✓		✓		✓			✓	✓			✓	✓	✓	✓						✓	✓		✓			✓
Walter's millet (Echinochloa walteri)	✓	✓	✓	✓		✓	✓	✓	✓	✓			✓	✓					✓		✓	✓			✓		✓

(Continued)

Table 6 (Concluded)

Species	Region: SA	Region: NA	Region: PP	Region: GC	Region: NC	Region: I	Soil Conditions: pH: Acid	pH: Neutral	pH: Alkaline	Salinity: Fresh	Salinity: Brackish	Salinity: Saline	Texture: Fine	Texture: Coarse	Marsh Moisture Conditions: Standing Water	Tidal: Low	Tidal: High	Interior: Low Fresh	Interior: High Fresh	Interior: Brackish	Wildlife Value: Food	Wildlife Value: Cover	Wildlife Value: Nesting/Breeding	Morphology: Perennial	Morphology: Annual	Potential Nuisance	Soil Stabilizer
Water hemp (*Acnida cannabina*)	✓		✓				✓	✓		✓			✓	✓				✓	✓		✓	✓		✓			✓
Water hyssop (*Bacopa caroliniana*)	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓			✓		✓			✓		✓			✓
Water lilies (*Nymphaea* spp.)	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓	✓	✓							✓		✓		✓	
Watermilfoils (*Myriophyllum* spp.)	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓	✓	✓						✓	✓		✓		✓	
Water nymphs (*Najas* spp.)	✓	✓	✓	✓	✓	✓	✓	✓			✓		✓	✓	✓							✓		✓		✓	
Water plantain (*Alisma plantago-aquatica*)	✓	✓		✓		✓	✓	✓		✓			✓	✓				✓	✓		✓	✓		✓			✓
Water shield (*Brasenia schreberi*)	✓		✓				✓	✓			✓		✓	✓	✓							✓		✓		✓	
Water smartweed (*Polygonum amphibium*)	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓	✓	✓			✓	✓		✓	✓		✓		✓	✓
Water willow (*Decodon verticillatus*)	✓	✓	✓	✓			✓	✓		✓			✓	✓					✓			✓		✓			✓
White mangrove (*Laguncularia racemosa*)			✓				✓	✓	✓		✓	✓	✓	✓	✓	✓						✓	✓	✓			✓
Widgeongrass (*Ruppia maritima*)	✓	✓	✓	✓	✓	✓		✓	✓		✓		✓	✓	✓	✓	✓				✓	✓		✓			
Wild celery (*Vallisneria americana*)	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓			✓			✓	✓		✓		✓	
Wild rice (*Zizania aquatica*)	✓	✓	✓	✓		✓	✓	✓		✓			✓	✓				✓	✓		✓	✓		✓			✓
Willows (*Salix* spp.)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓			✓	✓		✓	✓	✓	✓		✓	✓
Wolffias (*Wolffia* spp.)	✓	✓	✓	✓		✓	✓	✓	✓	✓			✓		✓						✓	✓		✓			
Yellow flag (*Iris versicolor*)		✓				✓	✓	✓		✓			✓	✓					✓			✓		✓			✓

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Table 7

Recommended Propagules and Techniques for Selected Marsh Species

Species	Recommended propagules	General collection, handling, and planting techniques	Remarks
Alkali bulrush	Transplants[1], tubers	Dig plants; divide; replant on site at same depth or pot for holding in nursery or greenhouse.	Seeds frequently eaten by waterfowl and other birds; used for soil stabilization; prefers fine soils.
Arrow arum[2]	Transplants, seeds	Dig plants; separate; replant at same depth on the site or pot for holding. Gather seeds when mature; store in freshwater at 1-3°C; broadcast on site and rake into soil.	Primarily a good soil stabilizer, although seeds are infrequently eaten by waterfowl and muskrats use it for lodge material. Potential pest plant.
Beak rush[2]	Seeds	Gather seeds when mature (July to September); store in freshwater at 5°C; broadcast on site and rake into soil.	Seeds eaten by [illegible]rfowl primarily.
Beggar's ticks[2]	Seeds	Gather seeds when mature (July to September); store dry at 5°C; broadcast on site and rake into soil.	Good food source for songbirds, game birds, and chicks. Potential pest.
Big cordgrass[2]	Transplants, seedlings	Dig young plants from natural stands; separate; replant on site at same depth or pot for holding. Germinate seeds and grow seedlings until ready for planting (3-6 months).	Excellent soil stabilizer in low, brackish marshes. Salinity prevents this species from competing with smooth cordgrass. Seeds eaten by all kinds of birds; rodents eat young tender foliage. Potential pest
Bigelow's glasswort[2]	Cuttings, rootstock	Collect 5-15 cm cuttings of top shoots and broadcast in wet area on the site. If must be stored, cuttings must remain moist. Dig rootstock; replant on site at same depth.	Low tidal area soil stabilizer. Tolerates fairly high salinities. Easily propagated. Poor source of wildlife foods. Occasionally used by nesting colonial seabirds.
Black mangrove[2]	Seeds, seedlings	Collect seed pods when mature (summer and fall); plant whole pod upright in soil with stem end up and out of the soil. Dig seedlings from natural stand or grow from seed pods.	Excellent soil stabilizer in south Florida. Frequently occurs on dredged material islands and used by colonial nesting wading bird specie. Tolerates to 40 ppt salinity.
Black needlerush[2]	Transplants	Dig clumps; divide into sections with a cutting device; replant on site at same depth or pot for holding.	Good high marsh soil stabilizer. Will not tolerate extended inundation and naturally occurs on tidal creek banks and high spots in the marsh. Seeds eaten by birds and small animals.
Bladderworts	Cuttings	Collect quantities of cuttings in buckets of water by scooping plants out of natural stands (in water); transfer to standing water on site.	Good waterfowl food source, especially for dabbling ducks. Potential pest plant in reservoirs.
Broadleaf arrowhead[2]	Transplants	Dig clumps; separate individuals; replant on site or pot for holding.	Good waterfowl food source; good cover for wildlife; muskrat food.
Bulrushes[2]	Transplants, tubers	Dig plants; divide; replant on site or pot for holding. Dig tubers; separate; cut off top shoots if present; replant on site or pot for holding.	Excellent waterfowl and songbird food (seeds); foliage eaten by muskrats; used for cover and breeding and nesting by many species.
Burreed[2]	Transplants	Dig plants; divide; replant on site or pot for holding.	Seeds infrequent source of wildlife food.
Buttercups	Cuttings	Collect quantities of cuttings in buckets of water by scooping plants out of natural stand(in water); transfer to standing water on site.	Good waterfowl food source. Potential pest plant in reservoirs.
Buttonbush[2]	Transplants, seeds	Dig small plants (large seedlings); transplant to site or pot for holding. Collect seeds in August-September; store seeds in freshwater at 5°C.	Seeds good source of food for waterfowl and other birds, insects, beavers, and muskrats. Provides cover and nesting habitat for birds
Chufa[2,3]	Tubers	Dig tubers when mature (July-Sept.); separate from other plant material; store moist but not wet at 5°C; broadcast on site and rake into soil. Tubers as very small and may be treated as seeds.	Excellent food source for waterfowl, turkeys, deer, wild boar, songbirds; highly productive plants may produce hundreds of tubers per plant. Seeds, tubers, foliage all relished.
Common reed[2]	Transplants, rootstock	Dig plants; divide; replant on site or pot for holding. Dig rootstock; separate into sections with at least one growth point, plant on site.	Used for nesting by songbirds, marsh birds, and waterbirds. Stabilizes soil; rapid growth with tall rank form. Definite pest plant.
Common threesquare[2]	Transplants, tubers	Dig plants, divide,replant on site at same depth or pot for holding. Dig tubers; divide; cut off top shoots if present; replant on site.	Good source of food for waterfowl, muskrats, and nutria. Used for soil stabilization.
Delta duckpotato[2,3]	Transplants	Dig plants, separate individuals; replant on site at same depth or pot for holding.	Excellent waterfowl food source; good soil stabilizer; only grows well on fine textured soils.
Dock[2]	Seeds	Collect seeds when mature (May to July); store dry at room temperature or less; plant broadcast on site and rake into soil.	Good food source for songbirds(seeds). Hardy species that is good soil stabilizer.
Dotted smartweed[2]	Seeds, cuttings	Collect seeds; store dry at room temperature or less; broadcast on site and rake into soil. Take cuttings from natural stand; broadcast on wet area on site (not standing water).	Good soil stabilizer; good cover for ducklings; seeds eaten by waterfowl, muskrats, and deer.

(Continued)

1 Transplants include plugs, groups of individuals, very large seedlings, and large whole plants.
2 Known to occur on dredged material. 3 Commercially available.

Table 7 (Continued)

Species	Recommended propagules	General collection, handling, and planting techniques	Remarks
Duckpotato [2]	Transplants	Dig plants; separate individuals; replant on site or pot for holding.	Excellent food source for waterfowl.
Duckweeds [2]	Whole plants	Collect buckets of plants from natural stand in water; place whole plants in standing permanent water on site.	Excellent food source for waterfowl, especially wood ducks. Good cover. In deep south can be pest in standing water that should be kept open.
Eel grass [2]	Transplants	Dig clumps with coring devices;replant in shallow seawater with a minimum of current and wave action.	Good soil stabilizer; food source for diving ducks; provides cover for marine organisms.
European glasswort [2]	Cuttings, rootstock	Take 5-15 cm cuttings from top shoots; broadcast on wet area of site. Dig rootstock; divide into clumps; replant on site at same depth.	Used primarily for soil stabilization. Poor wildlife food use; occasionally used by nesting colonial seabirds.
Fimbristylis [2]	Transplants, seeds	Dig plants; separate individuals; replant on site at same depth or pot for holding. Collect seeds when mature (July-Sept.); store dry; broadcast on site and rake into soil.	Fair food source for songbirds and occasionally for waterfowl.
Foxtail grasses [2]	Sprigs, seeds	Dig young plants; replant as sprigs on site at same depth or pot for holding as transplants. Collect seeds when mature (June-Oct.depending upon species); store dry at 5°C; broadcast on site.	Good source of food for most birds, browsers and grazers, rodents. Cover for many wildlife species.
Frankenia	Transplants	Dig plants; separate individuals; replant on site at same depth or pot for holding.	Soil stabilizer; poor source of food but some use as cover by wildlife.
Frog bit [2]	Seeds	Collect seeds when mature (July-Sept); store dry at room temperatures or less; broadcast on site and rake into soil.	Good seed source for songbirds; cover for small animals and birds; some use for stabilization.
Giant reed [2]	Seeds, transplants	Collect seeds when mature; store dry at room temperatures or less: broadcast on site and rake into soil. Dig plants; divide; replant on site or pot for holding.	Hardy plant; good seed source for wildlife; used for soil stabilization.
Groundsel tree [2]	Seedlings	Dig seedlings in natural stands; at least 0.3-0.5 m is minimum height for best survival; replant on site at same depth or pot for holding.	Excellent cover and nesting/breeding species; used frequently by colonial nesting wading birds on dredged material islands. Poor food source.
Hardstem bulrush [2]	Transplants, tubers	Dig plants; divide; replant on site or pot for holding. Dig tubers, divide from other plant material; cut off top shoots if present; plant on site at same depth.	Excellent seed source for birds; hardy species; used by muskrats and for soil stabilization.
Horned pondweed	Cuttings, rootstock	Gather plant material from standing water; place on site in permanent standing water areas. Dig rootstock from shallow water areas where possible; plant intact on site.	Fair food source for waterfowl, especially dabbling ducks; good sediment stabilizer.
Horsetails [2]	Transplants	Dig plants; separate individuals; replant on site or pot for holding.	Poor food source; only use is soil stabilization.
Japanese millet [2,3]	Seeds	Buy seeds from commercial seed source.	Excellent upland and marsh bird food; relished by waterfowl; eaten by turkeys, raccoons and other small animals, deer; Used in game management as food plot source
Ladysthumb [2]	Cuttings, seeds	Take cuttings 5-15 cm from top shoots; broadcast on wet area of site; rake into soil. Collect seeds when mature; store in fresh water; broadcast on site and rake into soil.	Excellent source of food for waterfowl and upland game and songbirds.
Lizard's tail [2]	Transplants, seeds	Dig plants; separate individuals; replant on site or pot for holding. Collect seeds when mature (June-Aug.); store in fresh water; broadcast on site and rake into soil.	Fair food source; used for stabilization in intermittent pond areas.
Lobelia	Transplants	Dig plants; separate individuals; replant on site or pot for holding.	Fair food source; possibly used for stabilization.
Lotus	Seeds, rootstock	Collect seeds when mature (Aug-Oct.); remove from pods; store in fresh water at 5°C; broadcast in shallow water on site. Dig rootstock when water is very low (late summer, fall); plant in shallow water on site.	Fair food source for waterfowl; relished by wild boar (roots); excellent cover for ducklings; potential pest in standing water and shallow reservoirs.
Lyngbye's sedge [2]	Transplants, seeds	Dig plants, separate individuals; replant on site or pot for holding. Collect seeds when mature (July-Sept.); store dry at room temperature; broadcast on site.	Good food source for waterfowl and other birds; good cover for many species.
Manna grass [2] (*G. acutiflora*)	Seeds, sprigs	Collect seeds when mature; store dry at room temperature or less; broadcast on site. Dig young plants for sprigs; replant on site or pot for holding as transplants.	Excellent seed source for many bird species; foliage eaten by small and large animals; good cover.
Manna grass [2] (*G. fluitans*)	Seeds, sprigs	Same procedures as above.	Excellent seed source for many bird species and other wildlife. good cover. Grows in wetter areas than above species.

(Continued)

Table 7 (Continued)

Species	Recommended propagules	General collection, handling, and planting techniques	Remarks
Marsh elder [2]	Seedlings	Dig seedlings in natural stands near parent plants; separate individuals; replant on site or pot for holding. Seedlings should be 0.3 m tall minumum.	Excellent cover species for birds and small animals; used by colonial nesting wading birds for nesting substrate. Potential pest plant.
Marsh hibiscus [2]	Seeds, tranplants	Collect seeds when mature (Aug-Oct); store dry at 5°C; plant on site at least 3-5 cm deep. Dig plants, replant on site or pot for holding.	Good cover for birds, sunning turtles; grows on banks of streams and ponds, in ditches; good soil stabilizer.
Marsh pepper [2]	Cuttings, rootstock	Take 5-15 cm cuttings from top shoots; broadcast on wet area of site; rake into soil. Dig rootstock; divide into sections; plant in wet area of site.	Excellent seed source for waterfowl and other birds; foliage bitter to browsers; good cover and soil stabilizer.
Marsh smartweed [2]	Cuttings, seeds	Cuttings: same as above. Collect seeds when mature (June-Sept); store or plant immediately on site; rake in soil.	Excellent seed source for waterfowl and other birds; good cover for many wildlife species.
Mud plantain [2]	Cuttings	Take 5-15 cm sections from top shoots; replant in mud and wet areas on site taking care to bury portions of cuttings in soil.	Good soil stabilizer in intermittent ponds and streams.
Nodding smartweed [2]	Seeds	Collect seeds when mature (June-Sept); store in fresh water at 5°C; broadcast on site; rake into soil.	Abundant seed source for upland and waterfowl birds; grows in drier soils than most smartweeds; potential pest.
Nutsedges [2]	Tubers, rootstock	Dig tubers in late summer and fall; divide; plant on site or pot for using as transplants. Dig rootstock; divide into sections; plant on site, same depth.	Excellent food source for most wildlife, especially chufa and red-rooted sedge; commercially available; potential pest in agronomic areas.
Olney's threesquare [2]	Transplants, tubers	Dig plants, separate individuals; plant on site or pot for holding. Dig tubers; separate; plant on site at same depth.	Excellent food source for waterfowl, muskrats, nutria, small animals. Good soil stabilizer.
Orache[2]	Seeds	Collect seeds when mature; store dry at room temperature or less; broadcast on site; rake into soil.	Good source of seeds for birds and rodents; good soil stabilizer.
Pacific cordgrass [2]	Transplants, sprigs	Dig young plants from edge of marsh; plant at same depth immediately as sprigs, or grow in pots and transplants into site as larger plants. Growing from seeds not recommended as seeds have very low viability rate.	Only low marsh soil stabilizer on west coast that tolerates both high salinities and strong tidal action. Good soil stabilizer; good cover; very slow growth.
Red mangrove [2]	Seeds, seedlings	Collect seed pods when mature; plant whole pod upright in soil with stem end up and out of the soil. Dig seedlings from natural stand or grow from seed pods.	Excellent soil stabilizer in south Florida. Frequently occurs on dredged material islands and used by colonial nesting wading birds for nesting. Tolerates sea-strength salinities.
Reed canary grass [1,3]	Seeds	Buy seeds from commercial seed source.	Excellent soil stabilizer; seeds good wildlife food source; used to dewater and filter waste water.
Reed grass [2]	Seeds, sprigs	Collect seeds when mature(July-Sept); store dry at 5°C; broadcast on site. Dig young plants to use for sprigs; separate individuals; plant on site or pot for growing as transplants.	Excellent seed source for birds; grazed heavily by mammals and rodents. Good soil stabilizer.
Reed manna grass [2]	Seeds, sprigs	Same procedures as above.	Same value as shown above.
Rice cutgrass [2]	Seeds, sprigs	Collect seeds when mature(May-July); store in fresh water at 5°C; broadcast on site and rake into soil(in wet areas). Dig young plants; separate individuals; plant on site at same depth in wet areas.	Good seed and foliage food source for many wildlife species, especially waterfowl and marsh birds. Good soil stabilizer of banks.
River bulrush [2]	Rootstock, transplants	Dig rootstock, divide into sections; plant at same depth on site. Dig plants; separate individuals; transplant to site or pot for holding.	Used frequently by nesting waterfowl and marsh birds; seed good food source for many wildlife species. Good soil stabilizer.
Rushes [2]	Transplants, rootstock, seeds	Dig plants; separate individuals; transplant to site or pot for holding. Dig rootstock; divide into sections, plant at same depth on site. Collect seeds when mature (July-Oct.); store in fresh water at 5°C; broadcast on site; rake into soil.	This group of plant species excellent for waterfowl, small animal, other birds' food; used as nesting substrate by waterfowl and marsh birds; good soil stabilizers; hardy plants.
Saltgrass [2]	Sprigs, rhizomes	Dig young plants; divide into sections; plant on site or pot for holding. Dig roots; divide rhizomes into small sections; plant on site; rake into soil.	Excellent soil stabilizer; grows well in high brackish marshes; used as lodge material by muskrats; seeds fair food source, but foliage poor source.
Saltmarsh aster [2]	Seeds	Collect seeds when mature (July-Sept); store dry at room temperature or less; broadcast on site; rake into soil.	Good soil stabilizer in high coastal marshes.
Saltmarsh bulrush [2]	Transplants, tubers	Dig plants; divide; plant on site at same depth or pot for holding; Dig tubers; separate tubers; cut off top shoots if present; plant on site at same depth.	Excellent food source for waterfowl and muskrats, nutria, other small animals. Good cover; good soil stabilizer; used by muskrats for lodge material.

(Continued)

(Sheet 3 of 5)

Table 7 (Continued)

Species	Recommended propagules	General collection, handling, and planting techniques	Remarks
Saltmarsh cattail [2]	Transplants, rootstock	Dig plants; separate individuals; plant on site at same depth. Dig roots; separate; cut off top shoots if present; plant on site.	Good soil stabilizer in brackish soils. Occurs in ditches, intermittent ponds, primarily on coasts. Low food value; fair cover.
Saltmarsh jaumea	Transplants	Dig plants, separate individuals; plant on site at same depth or pot for holding.	Fair soil stabilizer on west coast in high brackish marshes.
Saltmeadow cordgrass [2]	Transplants, sprigs	Dig plants; divide into clumps; plant on site at same depth or pot for holding. Dig young plants; separate; plant on site at same depth.	Excellent soil stabilizer in brackish marshes; also used in dune stabilization on Atlantic coast. Seed production often poor; low food value; some cover value.
Saw grass [2]	Sprigs, seeds	Dig young plants; separate individuals; plant on site or pot for holding. Collect seeds when mature (July-Sept); store in fresh water at 5°C; broadcast on site; rake into soil.	Species very site specific; occurs only in south Florida. Will not tolerate high nutrient levels. Good soil stabilizer; good cover; seeds eaten by some wildlife.
Sea lavender [2] (<u>L. carolinianum</u>)	Seeds	Collect seeds when mature (July-Aug); store dry at 5°C; broadcast on site; rake into soil.	Fair soil stabilizer; cover. Low food value. Some nesting substrate value.
Sea lavender [2] (<u>L. vulgare</u>)	Seeds	Same procedures as above.	Same values as above.
Sea ox-eye [2]	Transplants, seeds	Dig plants; separate indivuduals; plant on site at same depth or pot for holding. Collect seed heads when mature (July-Oct); store seeds in fresh water at 5°C; plant on site; rake into soil.	Excellent soil stabilizer; grows in high brackish marshes and on shores. Low food value; some cover and nesting value.
Sea purslane [2]	Seeds	Collect seeds when mature: store dry at room temperature or less; plant on site; rake into soil.	Fair soil stabilization value; low food value; some seed value as food. Some cover use.
Seaside arrowgrass [2]	Transplants	Dig plants, divide into individuals or clumps; plant on site at same depth or pot for holding.	Excellent soil stabilizer in brackish tidal marshes in Pacific northwest; some cover value; low food value.
Sedges [2]	Transplants, seeds	Dig plants; separate into clumps or individuals; plant on site or pot for holding. Collect seeds when mature (June-Sept); store dry at 5°C; broadcast on site; rake into soil.	This group of species far-ranging and widely varied. Usually excellent seed value for wildlife; also good cover. Prolific plants.
Shoal grass [2]	Transplants	Dig plugs with coring device in water at low tide; plant at site immediately at same depth.	Propagules must be stabilized to prevent tidal scour. Good cover value for marine organisms; good sediment stabilizer.
Slough grass [2]	Transplants, seeds	Dig plants; divide into clumps or individuals; plant at same depth on site or pot for holding. Collect seeds when mature (July-Sept); store in fresh water at 5°C; broadcast on wet site area.	Good food value for waterfowl and other seed-eating birds; foliage eaten by small animals. Good soil stabilizer.
Slough sedge [2]	Transplants, seeds	Dig plants; separate into clumps; plant on site at same depth or pot for holding; Collect seeds when mature (July-Oct); store in fresh water at 5°C; broadcast on wet site; rake into soil if necessary.	Excellent wildlife seed source; foliage also eaten. Good soil stabilizer.
Smartweeds [2]	Cuttings, seeds	Take 5-15 cm cuttings from top shoots; broadcast on site; rake into soil taking care to cover parts of cuttings (site should be wet). Collect seeds, store in fresh water or dry depending on species; broadcast on site; rake into soil.	Excellent group of plants for wildlife value; seeds readily consumed by waterfowl and many other birds and small animals. Good soil stabilizers.
Smooth cordgrass [2,3]	Sprigs, transplants	Dig young plants, separate individuals; plant as sprigs on site or pot to hold as trasplants. Dig transplants from natural marsh or grow from seeds; plant on site taking care to cover all roots.	Best soil stabilizer of low salt marshes on east and gulf coasts. Used extensively for stabilization and marsh creation projects. good cover value; good food value. Tolerant of tidal inundation for long periods.
Soft rush [2]	Transplants	Dig clumps; divide into sections with cutting device; plant on site at same depth or pot for holding.	Persistent high marsh species; good cover value. Some seed value, but foliage inedible. Known pest in pastoral areas.
Softstem bulrush [2]	Rhizomes, transplants	Dig roots; divide rhizomes leaving at at least one growth point on each; plant on site 2-5 cm deep. Dig plants; divide into sections; plant on site or pot for holding.	Excellent soil stabilizer of fresh water coastal and interior marshes. Good seed value for wildlife. Used as cover and nesting material by waterfowl and other wildlife.
Southern bulrush	Rhizomes, transplants	Same procedures as above.	Same values as above, except that this species does not occur as extensively as softstem bulrush, and grows much larger and robust.
Southern smartweed [2]	Cuttings, seeds	Take 5-15 cm cuttings from top shoots; broadcast in wet area on site; rake or place cuttings into soil. Collect seeds when mature (July-Oct); store in fresh water at 5°C; broadcast on site; rake into soil.	Excellent food source for waterfowl and marsh birds. Prolific growth habits; forms dense tall stands. Good cover value.
Southern cutgrass [2]	Seeds, sprigs	Collect seeds when mature (May-July); store in fresh water at 5°C; broadcast on wet site, rake into soil if necessary.	Excellent seed value for waterfowl and other birds; foliage eaten by small animals and grazers when tender and young. Good soil stab.

(Continued)

Table 7 (Concluded)

Species	Recommended propagules	General collection, handling, and planting techniques	Remarks
Spatterdock[2]	Transplants	Dig plants; separate individuals; plant on site at same depth or pot for holding.	Good waterfowl food; good soil stabilizer.
Spikerushes[2]	Transplants	Dig plants; divide into clumps; plant on site at same depth or pot for holding.	Excellent soil stabilizer; fair waterfowl food.
Spirodella[2]	Whole plants	Scoop buckets of plants from standing water; transfer to standing water on site.	Good waterfowl food, especially wood ducks.
Sprangletop[2]	Seeds, sprigs	Collect seeds when mature(summer,fall); store dry at room temperature or less; broadcast on site; rake into soil. Dig young plants; plant on site as sprigs.	Excellent seed source for wildlife; good soil stabilizer; used for cover.
Sweet flag	Transplants	Dig plants; divide individuals; plant on site in high marsh at same depth.	Good soil stabilizer; fair wildlife value; potential pest plant.
Tufted hairgrass[2]	Transplants, sprigs	Dig plants; divide individuals; plant on site or pot for holding. Dig young plants; plant as sprigs on site.	Excellent low marsh species for Pacific northwest; prolific growth; good cover and fair food wildlife value. Good soil stabilizer.
Turtle grass[2]	Transplants	Dig clumps with coring device from water at low tide; take care to be sure that at least one growth point is in each clump or will not reproduce: plant on site in the water.	Excellent cover and wildlife value; good cover for marine organisms. Species susceptible to environmental changes by man; rare in some areas.
Walter's millet[2,3]	Seeds	Buy from commercial seed source.	Excellent food value for waterfowl and other wildlife such as raccoons, turkey, deer, muskrats. Good temporary soil stabilizer.
Water hemp[2]	Seeds	Collect seeds when mature; store in fresh water at 5°C; broadcast in wet area on site; rake into soil if nec.	Good seed source for wildlife; fair soil stabilizer.
Water hyssop	Cuttings, sprigs	Take 5-15 cm cuttings from top shoots; plant in mud on site. Dig young plants; divide; plant on site in wet area.	Good soil stabilizer; fair wildlife food.
Water lilies[2,3]	Rootstock	Dig rootstock in late summer and fall when water levels are low; transplant to shallow water on site.	Good cover for ducklings; some food value. Excellent sediment stabilizer; potential pest.
Watermilfoils	Cuttings	Remove buckets of segments of plants from standing water; transfer to standing water on site.	Excellent dabbling duck food; good cover. Potential pest in standing water and reservoirs.
Water nymphs	Cuttings	Same procedures as above.	Same value as above.
Water plantain[2]	Transplants	Dig plants; divide individuals; plant on site at same depth.	Good food source for wildlife; fair soil stabilizer.
Water shield	Rootstock	Dig roots in shallow water in late summer and fall; transfer to standing shallow water on site.	Good cover value, good sediment stabilizer.
Water smartweed[2]	Cuttings, seeds	Take 5-15 cm cuttings from top shoots; plant on site in wet area taking care to bury part of cutting. Collect seeds when mature(July-Sept); store in fresh water at 5°C; broadcast on wet site.	Excellent waterfowl food; good cover. Excellent sediment and soil stabilizer.
Water willow	Transplants	Dig plants; divide individuals; plant on site at same depth.	Fair soil stabilizer; low wildlife value.
White mangrove[2]	Seeds, seedlings	Collect seeds when mature; plant immediately on site. Dig seedlings from natural stand; plant on site.	Excellent soil stabilizer; good cover; low food value; used by nesting birds.
Widgeongrass[2]	Cuttings	Remove buckets of segments of plants from standing water; transfer to standing water on site.	Excellent waterfowl food; grown by waterfowl managers for attracting waterfowl.
Wild celery	Whole plants	Remove whole plants from standing water; transfer to standing water on site.	Excellent cover value; harbors many invertebrates fed on by wildlife. Shades out aquatic plants; pest in Florida and deep south in some areas.
Wild rice[2]	Sprigs, seeds	Dig young plants, divide individuals; plant in shallow water on site. Collect seeds when mature; plant on wet site.	Low tolerance for pollution; must have fine-textured soils in slow-moving water. Excellent wildlife food, good soil stabilizer.
Willows[2]	Cuttings	Take 10-30 cm cuttings from dormant trees (winter months, early spring); plant on site with butt end 2/3 in soil.	Excellent soil stabilizer of stream and pond banks. Good cover and food value for songbirds. Very fast growing, potential pest.
Wolffias	Whole plants	Remove buckets of plants from standing water; transfer to standing water on site.	Excellent waterfowl food; good cover value.
Yellow flag	Transplants, rhizomes	Dig plants; divide individuals; plant in high marsh on site. Dig rhizomes; divide keeping one growth point on each rhizome; plant shallowly on site.	Good soil stabilizer, low wildlife value: showy flowers.

Sources of information used in the preparation of this table and Table 6 came from unpublished data by the author (Landin) and the following references: Adams (1963), Barbour and Davis (1970), Britton and Brown (1970), Brockman (1968), Broome et al. (1973), Burkhalter et al. (1974), Chabreck (1970), Correll and Johnston (1970), Duncan (1974), Eyles and Robertson (1963), Fassett (1960), Harris and Marshall (1960), Hitchcock (1950), Hotchkiss (1967), Hotchkiss (1970), Kadlec and Wentz (1974), Long and Lakela (1971), Martin et al. (1951), Mason (1969), Palmisano (1972), Radford et al. (1968), Salyer (1949), Seneca (1972), and Woodhouse et al. (1972).

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Table 8

Comparison of Advantages and Disadvantages of Propagules, by Source and Type

Basis of Comparison	Advantages	Disadvantages
Source:		
Nursery	Uniform quality Little or no disturbance of natural stands Reduces labor effort	May increase costs in certain situations Requires planning and ordering in advance May not be adapted to local conditions
Natural stand	Decreases costs Adapted to local conditions	Disrupts natural stands Can be difficult to locate sufficient supply Increases labor effort
Type:		
Seeds	Reduces labor and costs Suitable for large sites Can be stored for several months	Not suitable for fine-textured materials Wide range of viability, reliability, and success Storage requirements known for relatively few species Restricts harvest time Restricts planting time Cultivation generally required Requires advance planning to harvest and store supply
Tubers	Can be harvested mechanically if small Planting effort smaller (can be broadcast)	Large tubers difficult to extract from soil Susceptible to washout
Rootstocks, rhizomes	Maximizes use of plant materials	Susceptible to washout Cultivation generally required Limited success
Cuttings	Reduces labor and costs Rapid collection Maximizes use of plant materials	Susceptible to washout Must be planted promptly or potted and stored Some disruption of natural stand Lower survival than rooted propagules
Sprigs	Less costly than transplants	Must be planted promptly or potted and stored
Seedlings	Can be planted over longer periods Can be stored in greenhouse or nursery Permits flexibility in coordinating project engineering and planting	Requires planning and preparing in advance Increases costs
Transplants	Rapid establishment Increases probability of success, especially on salt marsh sites Stabilizes soil rapidly	Highest costs and labor requirements May be difficult to dig, transport, and plant

Increased ability to withstand physical stresses; increased costs

Table 9

Estimated Costs of Construction (adapted from Eckert et al. 1978)

Structure Type	Structure Height Above Bottom	Cost/linear m	Remarks and Assumptions
Sand dike hydraulically placed (1:3 slope)	3.0 m 6.0 m	$ 120.00 $ 345.00	For all construction in water. Low to moderate wave climate Costs of dredge mobilization not included in these figures Does not include any stone protection, nor establishment of vegetative cover
Earth dike, end-dumped construction (1:3 slope)	3.0 m 6.0 m	$ 240.00 $ 870.00	Method requires truck haul link to land, available material within a reasonable distance, and easy access to work site Length and width of dike are critical factors in truck cycle time and thus in cost Does not include any stone protection, nor establishment of vegetative cover
Rock dike, end-dumped 1-1/2 metric ton max (1:1 slope)	3.0 m 6.0 m	$1,200.00 $4,500.00	Material is quarry-run rock, not graded; placed as single layer
Steel sheet-pile bulkhead anchored wall	2.0 m	$1,440.00	Estimated PZ-27 sheets 10 m in length

(Continued)

Table 9 (Continued)

Structure Type	Structure Height Above Bottom	Cost/linear m	Remarks and Assumptions
			Sheets are mild steel with no corrosion protection
Wood sheeting bulkhead	3.0 m	$1,680.00	Treated timber piles, walers, and wood plank sheeting Price will vary greatly with location and availability of timber
Gabions	--	$ 115.00/m^3	Cost is in dollars per cubic metre Need to include volume of flexible apron in estimate Price dependent on availability of rock fill
Sandbag dike	1.5 m 3.0 m	$ 231.00 $ 825.00	Constructed in shallow water
Revetment: low-energy, rock gradation	--	$ 7.53/ centares	Small-size rock blanket, placed from land Assumes locally available source Filter required
Revetment: high energy, rock gradation	--	$ 31.78/ centares	Large stones placed by barge 220-km haul distance Filter required
Revetment: sandbags in single layer	--	$ 5.00/ centares	Conventional sandbags, no grout in fill Filter required
Revetment: gabion blanket 0.3 m thick	--	$ 20.90/ centares	Price is for freshwater gabion Filter required

Table 10

Man-Hours Required to Dig, Separate, and Transplant 1000 Plants of Each Species Used in Marsh Plantings on Texas Coast*

(adapted from Dodd and Webb 1975)

		Man-Hours Required			
Species	Planting Material	To Dig	To Separate	To Plant	Total
Saltgrass	1 to 5 sprigs with roots	1.4	1.3	8.6	11.3
Black needlerush	1 to 5 sprigs with rhizomes	1.5	1.3	8.9	11.7
Black mangrove	Seedlings 12-60 cm	3.7	0.0	8.3	12.0
Smooth cordgrass	1 sprig with roots	1.7	0.8	10.9	13.4
Gulf cordgrass	Small transplants	1.5	1.8	9.9	13.2
Saltmarsh bulrush	1 sprig with roots	5.7	1.5	10.7	17.9
Common reed	1 sprig with roots	5.2	1.8	11.5	18.5
Big cordgrass	1 sprig with roots	5.0	1.7	14.4	21.1
Common threesquare	1 tuber with roots	9.3	0.9	14.4	24.6
Giant reed	1 sprig with rhizomes	7.1	2.1	18.4	27.6
Olney's threesquare	Small transplants	4.1	4.9	20.3	29.3

* Multiply man-hours by 10 to obtain an estimate of man-hours/hectare on 1-m spacing.

Table 11

Man-Hours and Labor Costs for Digging and Planting
Marsh Species Transplants at Miller Sands
(from Ternyik 1978)

Species	Plants Dug and Planted per Man-Hour	Cost per Plant*	Man-Hours per 2,500 Plants**	Man-Hours per 10,000 Plants†	Man-Hours per 40,000 Plants††
Tufted hairgrass	115	$0.07	22	87	348
Slough sedge	104	$0.08	24	96	385
Lyngbye's sedge	104	$0.08	24	96	385
Soft rush	104	$0.08	24	96	385
Softstem bulrush	54	$0.15	46	185	741

* Computed at $8/man-hour, excluding equipment cost and travel time.
** Sufficient to plant 1 ha at 2-m spacing.
† Sufficient to plant 1 ha at 1-m spacing.
†† Sufficient to plant 1 ha at 0.5-m spacing.

Table 12

Seed Propagule Collection Costs for Intertidal Plantings at Miller Sands (from Ternyik 1978)

Species	Seeds Collected per Man-Hour	Seeds/kg	Man-Hours per kg*	Cost/kg**
Slough sedge	280,100	719,900	3	$ 15.42
Tufted hairgrass	1,389,300	2,450,300	2	$ 10.56
Lyngbye's sedge	75,400	630,000	8	$ 50.16
Softstem bulrush	31,300	692,000	19	$113.56
Broadleaf arrowhead	435,900	3,527,400	8	$ 48.54
Soft rush	Not available			

* Sowing time was less than 1 man-hour/ha for the entire site.

** Cost estimated at $6/man-hour excludes equipment cost and travel time.

APPENDIX A: DMRP REPORTS PERTINENT TO MARSH DEVELOPMENT

Report Title	DMRP Work Unit No(s).	U. S. Army Engineer Waterways Experiment Station Report Designation and No.	National Technical Information Service No(s).
		Environmental Impacts	
Transformations of Heavy Metals and Plant Nutrients in Dredged Sediments as Affected by Oxidation Reduction Potential and pH	1C05	Contract Report D-77-4	
Volume I: Literature Review*			AD A041 468
Volume II: Materials and Methods/ Results and Discussion*			AD A041 469
Trace and Toxic Metal Uptake by Marsh Plants as Affected by Eh, pH, and Salinity	4A06	Technical Report D-77-40	AD A050 914
*A Hydroponic Study of Heavy Metal Uptake by Selected Marsh Plant Species	4A15	Technical Report D-76-5	AD A033 224
Prediction of Heavy Metal Uptake by Selected Marsh Plants Based on Chemical Extraction of Heavy Metals from Dredged Material	4A15A	Technical Report D-78-6	--
Long-Term Release of Contaminants from Dredged Material	1E07	Technical Report D-78-49	--
Field Bioassay Test for Detecting Contaminate Uptake from Dredged Material by Marsh Plants	42A6	Miscellaneous Paper D-78-6	--
Availability of Sediment-Adsorbed Heavy Metals to Benthos with Particular Emphasis on Deposit-Feeding Infauna	1D06	Technical Report D-78-42	--
Vertical Migration of Benthos in Simulated Dredged Material Overburdens	1D03	Technical Report D-78-35	--
Effects of Dredging and Disposal on Aquatic Organisms	1D13	Technical Report DS-78-5	--
Mineral Cycling in Salt Marsh-Estuarine Ecosystems	2A05	Technical Report D-78-3	--
The Effects of Smothering a Spartina Alterniflora Salt Marsh with Dredged Material	2A07	Technical Report D-78-38	--
		Productivity and Succession	
*Primary Productivity of Minor Marsh Plants in Delaware, Georgia, and Maine	4A04A1	Technical Report D-77-36	AD A051 164
Common Marsh Plant Species of the Gulf Coast Area	4B04B	Technical Report D-77-44	
Volume I: Productivity			AD A052 094
Volume II: Growth Dynamics			AD A052 095
Underground Biomass Dynamics and Substrate Selective Properties of Atlantic Coastal Salt Marsh Plants	4A04A2	Technical Report D-77-28	AD A055 761
Modeling of Ecological Succession and Production in Estuarine Marshes	4A05	Technical Report D-77-35	AD A051 929
		Planning	
*Identification of Objectionable Environmental Conditions and Issues Associated with Confined Disposal Areas	2C06	Contract Report D-74-4	AD A000 895
*Identification of Relevant Criteria and Survey of Potential Application Sites for Artificial Habitat Creation, Volumes I and II	4A01	Contract Report D-76-2	AD A033 525
Dredged Material Transport Systems for Inland Disposal and/or Productive Use Concepts	3B01	Technical Report D-78-28	--
*Guidelines for Material Placement in Marsh Creation	4A08	Contract Report D-75-2	AD 010 725
		Engineering	
Classification and Engineering Properties of Dredged Material	5C02	Technical Report D-77-18	--
Design Concepts for In-Water Containment Structures for Marsh Habitat Development	4A07A	Technical Report D-78-31	--

(Continued)

* Report is out of print but can be purchased from the National Technical Information Service (5285 Port Royal Road, Springfield, Va. 22151). In requesting copies from NTIS, the NTIS number should be included if given. The telephone number of NTIS is Area Code 703 557-4650 (FTS access number + 557-4650).

Report Title	DMRP Work Unit No(s).	U. S. Army Engineer Waterways Experiment Station Report Designation and No.	National Technical Information Service No(s).
	Engineering (Continued)		
Guidelines for Designing, Operating, and Managing Dredged Material Containment Areas	2C18	Technical Report DS-78-10	--
Assessment of Low-Ground-Pressure Equipment for Use in Containment Area Operation and Maintenance	2C09	Technical Report DS-78-9	--
Design and Construction of Retaining Dikes for Containment of Dredged Material	2C04	Technical Report D-77-9	AD A045 311
Weir Design to Maintain Effluent Quality From Dredged Material Containment Areas	2C19	Technical Report D-78-18	--
	Plant Propagation		
Pregermination Requirements and Establishment Techniques for Salt Marsh Plants	4A09	Miscellaneous Paper D-77-1	AD A045 514
Influence of Pregermination Conditions on the Viability of Selected Marsh Plants	4A21	Technical Report D-78-51	--
*State-of-the-Art Survey and Evaluation of Marsh Plant Establishment Techniques: Induced and Natural	4A03	Contract Report D-74-9	AD A012 837
*Establishment and Growth of Selected Freshwater and Coastal Marsh Plants in Relation to Characteristics of Dredged Sediments	4B06	Technical Report D-77-2	AD A039 495
	Field Studies		
Habitat Development Field Investigations, Windmill Point Marsh Development Site, James River, Virginia: Summary Report	4A11M	Technical Report D-77-23	--
Appendix C: Environmental Impacts of Marsh Development with Dredged Material: Acute Impacts on the Macrobenthic Community	4A11K	Technical Report D-77-23	AD A055 319
Appendix D: Environmental Impacts of Marsh Development with Dredged Material: Botany, Soils, Aquatic Biology, and Wildlife	4A11I	Technical Report D-77-3	--
Appendix E: Environmental Impacts of Marsh Development with Dredged Material: Metals and Chlorinated Hydrocarbon Compounds in Marsh Soils and Vascular Plant Tissues	4A11L	Technical Report D-77-23	--
Appendix F: Environmental Impacts of Marsh Development with Dredged Material: Sediment and Water Quality	4A11DGH	Technical Report D-77-23	--
Habitat Development Field Investigations, Buttermilk Sound Marsh Development Site, Atlantic Intracoastal Waterway, Georgia: Summary Report	4A12A	Technical Report D-78-26	--
Appendix A: Propagation of Marsh Plants and Postpropagation Monitoring	4A12A	Technical Report D-78-26	--
Habitat Development Field Investigations, Bolivar Peninsula Marsh and Upland Habitat Development Site, Galveston Bay, Texas: Summary Report	4A13K	Technical Report D-78-15	--
Appendix D: Propagation of Vascular Plants and Postpropagation Monitoring of Botanical, Soil, Aquatic Biota, and Wildlife Resources	4A13F	Technical Report D-78-15	--
Habitat Development Field Investigations, Rennie Island Marsh Development Site, Grays Harbor, Washington: Summary Report	4A14D	Technical Report D-78-11	--

(Continued)

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Report Title	DMRP Work Unit No(s).	U. S. Army Engineer Waterways Experiment Station Report Designation and No.	National Technical Information Service No(s).
		Field Studies (Continued)	
Feasibility Study for Dyke Marsh Demonstration Area, Potomac River, Virginia	4A17	Technical Report D-76-6	A033 524
Detailed Design for Dyke Marsh Demonstration Area, Potomac River, Virginia	4A17A	Technical Report D-77-13	AD A048 179
Habitat Development Field Investigations, Salt Pond No. 3 Marsh Development Site, South San Francisco Bay, California: Summary Report	4A18A	Technical Report D-78-57	--
Habitat Development Field Investigations, Apalachicola Bay Marsh Development Site, Apalachicola Bay, Florida: Summary Report	4A19A	Technical Report D-78-32	--
Habitat Development Field Investigations, Miller Sands Marsh and Upland Habitat Development Site, Columbia River, Oregon: Summary Report	4B05M	Technical Report D-77-38	--
Appendix E: Postpropagation Assessment of Botanical and Soil Resources on Dredged Material	4B05K	Technical Report D-77-38	--
Appendix F: Postpropagation Assessment of Wildlife Resources on Dredged Material	4B05I	Technical Report D-77-38	AD A056 823
		General	
Upland and Wetland Habitat Development with Dredged Material: Ecological Considerations	2A08	Technical Report DS-78-15	--
*Recent and Planned Marsh Establishment Work Throughout the Contiguous United States - A Survey and Basic Guidelines	4A25	Contract Report D-77-3	AD A041 464

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APPENDIX B: COMMON AND SCIENTIFIC NAMES OF PLANTS AND ANIMALS MENTIONED IN THE TEXT, APPENDICES, AND TABLES*

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* Animal taxonomy is based on American Ornithologists' Union (1957, 1973, 1976) and Jones et al. (1975). Plant taxonomy is based on Britton and Brown (1970), Correll and Johnston (1970), Hitchcock (1950), Hotchkiss (1967, 1970), Long and Lakela (1971), and Radford et al. (1973).

Common Name	Scientific Name
Alkali bulrush	*Scirpus paludosus*
Alligator weed	*Althernanthera philoxeroides*
American elm	*Ulmus americana*
Arrow arum	*Peltandra virginica*
Australian pine	*Casuarina equisetifolia*
Beach panic grass	*Panicum anceps*
Beak rush	*Rynchospora tracyi*
Beggar's ticks	*Bidens* spp.
Big cordgrass	*Spartina cynosuroides*
Bigelow's glasswort	*Salicornia bigelovii*
Black mangrove	*Avicennia nitida*
Black needlerush	*Juncus romerianus*
Black willow	*Salix nigra*
Bladderworts	*Utricularia* spp.
Brazilian pepper	*Schinus terebinthifolius*
Broadleaf arrowhead	*Sagittaria latifolia*
Broadleaf cattail	*Typha latifolia*
Bulrushes	*Scirpus* spp.
Burreed	*Sparganium americanum*
Buttercups	*Ranunculus* spp.
Buttonbush	*Cephalanthus occidentalis*
Buttonwood	*Conocarpus erecta*
Cabbage palm	*Sabal palmetto*
Chufa	*Cyperus esculentus*
Coastal bermuda grass	*Cynodon dactylon* hybrid
Common bermuda grass	*Cynodon dactylon*
Common reed	*Phragmites australis*
Common threesquare	*Scirpus americanus*
Delta duckpotato	*Sagittaria platyphylla*
Dock	*Rumex* spp.
Dotted smartweed	*Polybonum punctatum*
Duckpotato	*Sagittaria cuneata*
Duckweeds	*Lemna* spp.

Common Name	Scientific Name
Eastern cottonwood	*Populus deltoides*
Eel grass	*Zostera marina*
European glasswort	*Salicornia europea*
Fimbristylis	*Fimbristylis castanea*
Foxtail grasses	*Setaria* spp.
Frankenia	*Frankenia grandifolia*
Frog bit	*Limnobium spongia*
Giant reed	*Arundo donax*
Groundsel tree	*Baccharis halimifolia*
Gulf cordgrass	*Spartina spartinae*
Gum plant	*Grindelia integrifolia*
Hackberry	*Celtis occidentalis*
Hardstem bulrush	*Scirpus acutus*
Horned pondweed	*Zannichellia palustris*
Horsetails	*Equisetum* spp.
Ice plant	*Mesembryanthemum crystallinum*
Japanese millet	*Echinochloa crus-galli*
Ladysthumb	*Polygonum persicaria*
Live oak	*Quercus virginiana*
Lizard's tail	*Saururus cernuus*
Lobelia	*Lobelia dortmanna*
Lotus	*Nelumbo lutea*
Lyngbye's sedge	*Carex lynbyei*
Manna grass	*Glyceria acutiflora*
Manna grass	*Glyceria fluitans*
Marsh elder	*Iva frutescens*
Marsh hibiscus	*Hibiscus moscheutos*
Marsh pepper	*Polygonum hydropiper*
Marsh smartweed	*Polygonum hydropiperiodes*
Mud plantain	*Heteranthera reniformis*
Nodding smartweed	*Polygonum lapathifolium*
Nutsedges	*Cyperus* spp.
Olney's threesquare	*Scirpus olneyi*

Common Name	Scientific Name
Orache	*Atriplex patula*
Pacific cordgrass	*Spartina foliosa*
Pacific glasswort	*Salicornia pacifica*
Pacific sedge	*Carex obnupta*
Pacific wax myrtle	*Myrica californica*
Palmetto	*Serena repens*
Panic grasses	*Panicum* spp.
Paspalum grasses	*Paspalum* spp.
Pennsylvania smartweed	*Polygonum pensylvanicum*
Pennyworts	*Hydrocotyle* spp.
Pickerelweed	*Pontederia cordata*
Pondweeds	*Pontonogoton* spp.
Prairie cordgrass	*Spartina pectinata*
Red mangrove	*Rhizophora mangle*
Red maple	*Acer rubrum*
Red-rooted sedge	*Cyperus erythrorhizos*
Redtop	*Agrostis alba*
Reed canary grass	*Phalaris arundinacea*
Reed grass	*Calamogrostis canadensis*
Reed manna grass	*Gylceria grandis*
Rice cutgrass	*Leersia oryzoides*
River bulrush	*Scirpus fluviatilis*
Rushes	*Juncus* spp.
Saltgrass	*Distichlis spicata*
Saltmarsh aster	*Aster tenuifolius*
Saltmarsh bulrush	*Scirpus robustus*
Saltmarsh cattail	*Typha angustifolia*
Saltmarsh Jaumea	*Jaumea carnosa*
Saltmeadow cordgrass	*Spartina patens*
Saltwort	*Salsola kali*
Saw grass	*Cladium jamaicense*
Sea grape	*Coccoloba uvifera*
Sea lavender	*Limonium carolinianum*

Common Name	Scientific Name
Sea lavender	*Limonium vulgare*
Sea oxeye	*Borrichia frutescens*
Sea purslane	*Sesuvium portolacastrum*
Seaside arrowgrass	*Triglochin maritima*
Seaside goldenrod	*Solidago sempervirens*
Sedges	*Carex* spp.
Shoal grass	*Halodule wrightii*
Sitka alder	*Alnus sinuata*
Sitka spruce	*Picea sitchensis*
Slash pine	*Pinus elliottii*
Slough grass	*Beckmannia syzigachne*
Slough sedge	*Carex trichocarpa*
Smartweeds	*Polygonum* spp.
Smooth cordgrass	*Spartina alterniflora*
Soft rush	*Juncus effusus*
Softstem bulrush	*Scirpus validus*
Southern bulrush	*Scirpus californicus*
Southern cutgrass	*Zizaniopsis mileacea*
Southern smartweed	*Polygonum densiflorum*
Spatterdock	*Nypha lutum*
Spikerushes	*Eleocharis* spp.
Spirodella	*Spirodella polyrhiza*
Sprangletop	*Leptochloa fascicularis*
Sweet flag	*Acorus calamus*
Switchgrass	*Panicum virgatum*
Tall fescue	*Festuca elatior*
Telegraph weed	*Heterotheca grandiflora*
Tufted hairgrass	*Deschampsia caespitosa*
Turtlegrass	*Thalassia testudinum*
Walter's millet	*Echinochloa walteri*
Water hemp	*Acnida cannabina*
Water hyacinth	*Eichornia crassipes*
Water hysoop	*Bacopa caroliniana*

Common Name	Scientific Name
Water lilies	*Nymphaea* spp.
Watermilfoils	*Myriophyllum* spp.
Water nymphs	*Najas* spp.
Water oak	*Quercus nigra*
Water plantain	*Alisma plantago-aquatica*
Water primrose	*Jussiaea leptocarpa*
Water shield	*Brasenia schriberi*
Water smartweed	*Polygonum amphibum*
Water willow	*Decodon verticillatus*
Wax myrtle	*Myrica cerifera*
White mangrove	*Laguncularia racemosa*
Widgeongrass	*Ruppia maritima*
Wild celery	*Vallisneria americana*
Wild rice	*Zizania aquatica*
Willows	*Salix* spp.
Wolffia	*Wolffia* spp.
Yellow flag	*Iris versicolor*
Yaupon	*Ilex vomitoria*

Animals

Canada goose	*Branta canadensis*
Cow	*Bos indicus*
Deer	*Odocoileus* spp.
Goat	*Capra hircus*
Muskrat	*Ondatra zibethicus*
Northern shoveler	*Anas clypeata*
Nutria	*Myocastor coypus*
Rabbit	*Sylvilagus* spp.
Raccoon	*Procyon lotor*
Sheep	*Ovis aries*
Turkey	*Meleagris gallopavo*
Wood duck	*Aix sponsa*

APPENDIX C: SPECIES SYNOPSES

The following 28 species are identified as those which may be recommended for planting on dredged material marsh sites. There are many other freshwater marsh species which are probably suitable. However, little work with those species has been conducted on dredged material and their acceptance of the dredged material substrate is not known at this time. A list of these other species with pertinent information is presented in Tables 6 and 7 in the text.

Arrow Arum (*Peltandra virginica*)

Description: Perennial herb in dense clumps from 30 to 45 cm high, without true stem, leaves basal; leaves bright green, arrow-shaped, thick, strongly veined, about 20 cm wide and up to 75 cm long; flowers May to June, fleshy; seeds in pod-like case, dark green, and berry-like.

Range: Ontario, Michigan, coastal Maine, and throughout southeast and deep south.

Habitat: Freshwater wetlands on loose rich silt; marshes and margins of interior and coastal lakes and streams.

Associated species: Pickerelweed.

Establishment: By seeds or transplants.

Seeds. Collect mature seeds from stalks, and store dry at 5°C. Sow onto the site in spring and summer.

Transplants. Dig clumps and divide out individual plants; do not cut or separate clump as the species does not have true stems and will not tolerate this treatment. Individual plants are difficult to sort but still the best method of rapid propagation.

Value: Poor seed food value for most wildlife but is relished by wood ducks; sometimes seeds high in oxalic acid; eaten by king rails and muskrats; some food value for muskrats.

Comments: Potential nuisance through tendency to invade.

Big Cordgrass (*Spartina cynosuroides*)

Description: Perennial grass, from 2 to 4 m tall, from vigorous rhizomes; leaves wide (2.5 to 3 cm), long and tapering with upturned teeth; flowers August to October; seed heads large and multibranched.

Range: Texas to Massachusetts.

Habitat: Brackish and high coastal salt marshes; margins of tidal streams and freshwater areas.

Associated species: Common reed and black needlerush.

Tolerance: Tolerates pH of 4.3 to 6.9, inundation, brackish waters; does not tolerate highly saline conditions; susceptible to oil and grease contamination.

Establishment:

Seeds. Should be shattered from seed heads and stored in distilled water or salt solutions (10 to 35 ppt).

Transplants. Dig plants, divide, replant onto the site or pot for holding.

Value: Fair food value for waterfowl and muskrats; cover for waterfowl; used by muskrats for lodge construction.

Comments: Potential nuisance; best established at or above mean high water.

Black Needlerush (*Juncus roemerianus*)

Description: Perennial rush in dense stands of nearly uniform height, 0.5 to 1.5 m high, and characteristically dark green to gray black; leaves and stems rigid, round, and sharp-pointed; flowers May to October in green to brown clusters arising from side of stem.

Range: Coast from Texas to Maryland.

Habitat: Brackish and saltwater marshes above the intertidal zone in silty clays, sands, and loams; infrequently in freshwater marshes.

Tolerance: Tolerates pH of 4.3 to 9.5 and oil and grease contamination.

Associated species: Saltmeadow cordgrass, big cordgrass.

Establishment: By transplants consisting of at least one node and associated stems and roots. Dig clumps and divide into sections or individual sprigs for transplanting.

Value: Low wildlife value; of some value in nitrogen fixing and soil stabilization.

Comments: Very resistant to erosion; good regenerative capability; frequently colonizes dredged material banks; grows rapidly and continues growing throughout the winter; potential nuisance.

Broadleaf Arrowhead (*Sagittaria latifolia*)

Description: Perennial aquatic herb about 1.2 to 2 m tall, from fibrous tubers; leaves slender, spear-like, dark-green, up to 30 cm long; flowers July to September, white, tri-petalled.

Range: Southern Canada and throughout most of the U. S.

Habitat: Inland and coastal freshwater marshes; margins of lakes and ponds; organic, silty substrates.

Tolerance: Tolerates pH of 5.9 to 8.8, turbidity, and moderate pollution.

Associated species: Arrow arum, pickerelweed.

Establishment:

Seeds. Collect when mature and store wet at 1 to 3°C.

Transplants. Dig plants; separate, transplant immediately onto the site, or hold in pots.

Value: High food value for a variety of wildlife, especially waterfowl.

Comments: Showy flowers; good regeneration; slow to moderate growth rate.

Cattails (*Typha* spp.)

Description: Emersed perennials in colonies from stout, horizontal branching rootstock; leaves ribbon-like; flowers May to July; fruits June to November in characteristic spike.

Saltmarsh cattail (*Typha angustifolia*): Narrow-leaved cattail, has leaves 0.6 to 1.0 cm wide; spike usually characterized by distinct gap between upper and lower portions.

Broadleaf cattail (*Typha latifolia*): Broad-leaved cattail; has leaves up to 4.0 cm wide and usually no gap on its spike.

Range: Throughout the U. S.

Habitat: Brackish and freshwater marshes; shallow waters of lakes, ponds, river banks, and ditches.

Tolerance: Saltmarsh cattail tolerates pH of 3.7 to 8.5 and slightly brackish marshes; broadleaf cattail tolerates pH of 4.5 to 9.0. Apparently tolerant of turbidity and moderate pollution.

Associated species:

With saltmarsh cattail: common reed, big cordgrass.

With broadleaf cattail: smartweed, soft rush, a variety of freshwater submergent and emergent marsh species.

Establishment:

Seeds. Store seeds dry at room temperatue; they go through dormant period, but can give 100 percent germination if seed coat is ruptured.

Transplants. Dig plants, separate individuals, replant on site or hold in pots. Planting within a few weeks is recommended.

Value: Seeds poor food value; rootstocks eaten by geese and muskrats; cover for birds; used for nesting by many waterbird and waterfowl species.

Comments: Extensive cover undesirable in marshes intended primarily for ducks; require rhizome aeration for overwinter survival; edible by humans.

Chufa (*Cyperus esculentus*)

Description: Perennial nutsedge to 0.6 m from abundant tubers; leaves slightly folded and narrow; lush growth; forms dense stands; seeds July to October.

Range: Throughout U. S.

Habitat: Freshwater marshes in all soils; prefers silts, or silty sands, and loams.

Tolerance: Will not tolerate drought and does poorly in sandy soil; pH range of 5.0-7.5.

Associated species: Sedges, other nutsedges, switchgrass, rushes.

Establishment:

Tubers. Dig mature tubers in July through September and either replant on the site or store in plastic bags at 5°C. Transplants and seeds are not as cost efficient as tubers, since digging transplants is expensive and seeds are variable.

Value: Very high value as food for waterfowl, muskrats, nutria, songbirds, deer, and turkey.

Comments: Easily established and commercially available.

Common Reed (*Phragmites australis*)

Description: Perennial grass, 1 to 5 m tall from long, scaly, creeping rhizomes; stems coarse, hard, and erect; leaves 0.6 m long and flat-bladed; flowers July to September; feathery seed heads up to 40 cm.

Range: Widespread throughout U. S., especially northeast and east.

Habitat: Low to brackish salinity marshes and freshwater areas along lakes and streams and in estuaries but not in permanent marshes; generally associated with disturbed areas; grows in sand, silts, and peaty sands.

Tolerance: Tolerates pH of 3.7 to 9.0; cannot tolerate salinity of upper tidal zone over 20 ppt or temporary water depths of over 15 cm; tolerates late summer drought but requires shallow spring flooding.

Establishment: By transplant sprigging in early spring and by rhizomes. Not recommended for establishment in tidal zone. Requires a wet soil but no more than 1 cm water for establishment.

Value: No food value for wildlife but provides cover; useful in flood control, sediment stabilization, and water quality improvement.

Comments: Should be planted only where stabilization is critical and where growth can be controlled; aggressive rhizomes, extending up to 10 m, vegetate areas quickly and may outcompete other more valuable species.

Fimbristylis (*Fimbristylis castanea*)

Description: Perennial grass; culms wiry, 0.3 to 1.0 m tall; leaves pale, firm; flowers July to October; nutlets whitish or yellowish.

Range: Coast from Texas to Long Island, but mainly Florida to Virginia.

Habitat: Coastal brackish marshes, savannahs, and meadows; averages about 90 cm above mean sea level.

Tolerance: Tolerates pH of 5.4 to 7.8.

Establishment: By plugs. Seeds are difficult to germinate. Dig sections or entire plants for relocation on the site.

Value: Seeds are eaten by waterfowl and rodents.

Lyngbye's Sedge (*Carex lyngbyei*)

Description: Perennial sedge from long, stout rhizomes; forms large 20- to 40-cm high clumps; flowers July to August.

Range: West coast from Alaska to California; east coast from Greenland to Quebec.

Habitat: Coastal brackish and salt marshes.

Tolerance: Salinity 0-20 ppt; pH ranges of 5.5-8.0.

Associated species: Tufted hairgrass, rushes, bulrushes, seaside arrowgrass, and other sedges.

Establishment: Natural establishment by rootstock and seed; artificial establishment by transplants from natural stands. Artificial establishment with seeds not recommended.

Value: Various plant parts eaten by many species of wildlife, especially sparrows, rails, dabbling ducks, buntings, rodents, and browsing mammals. Valuable cover for wildlife, nesting cover for ducks and geese.

Comments: Frequently invades disturbed areas by rooting of rafted plants.

Marsh Elder (*Iva frutescens*)

Description: Perennial shrub from 1.5 to 3.5 or 5.0 m tall; stems partly woody; leaves opposite below but alternate on upper stem; narrow, pointed, toothed, and fleshy; flowers diminutive, greenish-white heads in clusters at tip of stems.

Range: Coast from Mexico to Canada.

Habitat: High salt marsh; upland margins or small hummocks in salt or brackish marshes; common on dredged material islands.

Tolerance: Tolerates pH of 6.0 to 7.5.

Associated species: Groundsel tree, wax myrtle.

Establishment:

Seeds. Harvest seed by collecting mature heads; store up to 180 days in fresh or distilled water. Germinates best at 10 to 25°C although viability is low.

Transplants. Collect small plants for transplanting onto the site. These are often abundant as seedlings near parent plants.

Value: Nesting for herons, egrets, and other colonial tree-nesting birds.

Comments: Difficult to harvest seed in quantity.

Olney Threesquare (*Scirpus olneyi*)

Description: Perennial sedge; stems erect to 1.2 m high, three-sided; flowers June to September.

Range: Atlantic and gulf coasts and parts of the interior U. S.

Habitat: Shallow water of brackish marshes and pools; organic and clay substrates.

Associated species: Common threesquare, saltmarsh bulrush, saltgrass.

Tolerance: tolerates pH of 3.7 to 6.9, oil and grease contamination.

Establishment: By transplants, tubers, and seeds.

Seeds. Store dry at room temperature or cooler; soaking in freshwater prior to planting improves germination.

Transplants and tubers. Dig, separate into individual plants and transplant onto site or hold in pots. For tubers, cut off growing shoots (if present), and plant. Top will regenerate.

Value: Little food value for ducks, high food value for muskrats; shelter for rails.

Comments: Seldom occurs in pure stands.

Pacific Cordgrass (*Spartina foliosa*)

Description: Perennial grass, 0.3 to 1.3 m tall from extensive creeping, scaly, ridged rhizomes; stems winter dormant; leaves flat, about 15 to 40 cm long and 8 to 12 mm wide at the base; flowers August to October; seed heads short, upright, and unbranched with slightly twisted spikes.

Range: Intermittent on California and Baja coasts; rarely occurs north of San Francisco.

Habitat: Salt marshes and tidal flats, typically below mean higher high water on clay substrates.

Tolerance: Tolerates broad range of intertidal environments, high salinities, and up to 21 hrs of flooding.

Associated species: Pacific glasswort.

Establishment: By transplants and seeds.

Seeds. Collect mature seed heads, shatter, and store in cold (5°C) fresh or salt water; change water every 2 weeks and do not close containers.

Transplants. Dig young plants from natural marsh; separate individuals; replant onto site or hold in pots.

Seedlings. Germinate seeds in peat pots containing marsh soils; plant on the site at 4 to 12 months of age, depending upon size.

Value: Fair source of food for waterfowl; used primarily for soil stabilization.

Comments: Plantings practical between mean higher high water and mean tide level and at salinities of 10 to 40 ppt; aggressive but very slow vegetative reproduction.

Pacific Glasswort (*Salicornia pacifica*)

Description: Perennial, prostrate or erect from 25 to 30 cm high from spreading rhizomes; stems partially woody, succulent, jointed, constricted at nodes, occasionally roots along prostrate branches; leaves obscure and united into collar-like structure; seed-containing stem tips turn red when mature.

Range: West coast.

Habitat: Coastal and inland salt marshes between 2.5 and 3.8 m above mean lower low water in soils of 18 ppt or greater salinity; sparingly in wet saline or alkaline floodlands.

Tolerance: Tolerates pH 4.7 to 8.5; high tolerance of salinity (up to 80 ppt) and inundation; tolerates oil and grease.

Associated species: Pacific cordgrass.

Establishment: By rootstock, rooted or unrooted cuttings, and less often by seed.

Cuttings. Consist of 10- to 15-cm-long pieces of terminal and upright branches. Root in peat pots containing sand and sediment from native stand. Plant unrooted cuttings by scattering over site (1.6 ℓ/m^2) and raking into surface.

Seeds. Difficult to collect but do not go through dormancy and remain viable up to 180 days.

Rootstock. Dig roots, separate, plant on site or pot to hold for transplants.

Value: Some food value for ducks and geese; primarily for soil stabilization.

Comments: Doubtful that artificial propagation is warranted; because of weedy nature it rapidly invades without encouragement if a propagule source is in the vicinity.

Saltgrass (*Distichlis spicata*)

Description: Perennial grass from creeping rhizomes of dense growth 0.1 to 0.6 or 1.0 m tall; stems stiff, brittle, and erect; leaves on opposite sides of stem, short, trough-shaped, and pale; flowers August to September, loosely compacted head.

Range: Nova Scotia to Texas; British Columbia to California.

Habitat: Coastal salt or brackish water marshes, particularly from 30 cm below to 150 cm above mean sea level in silty clays, sands, and clays. Also frequent in interior salt and alkali marshes.

Tolerance: Tolerates wide range of soil moisture and salinity; frequent tidal inundation, pH range from 4.1 to 9.5.

Associated species: Saltmeadow cordgrass.

Establishment: By transplants, rhizomes, seeds, and plugs. Transplanting optimal in October and January through March. Along the Gulf, rhizome propagation successful in spring and summer. Harvest seeds in fall and store dry at room temperature. Transplants are dug and divided into individuals, then transplanted onto site or into peat pots for holding.

Value: Seeds fair value for waterfowl and other birds; nesting cover for waterfowl; valued for substrate stabilization in coastal areas.

Comments: Forms dense colonies; invades sand overwash areas and tidally washed disposal sites; adapted for use in area between low tide and near high tide.

Saltmarsh Bulrush (*Scirpus robustus*)

Description: Perennial sedge about 0.7 to 1.5 m tall from shallowly rooted rhizomes; leaves deep green, 4 to 10 mm wide, prominently ribbed, and usually taller than the main stem; flowers from July to October in end clusters.

Range: Throughout U. S., but more commonly in coastal areas and west of the Mississippi River.

Habitat: Brackish marshes and ponds in organic and clay soils.

Associated species: Olney threesquare, common threesquare, saltmeadow cordgrass, saltgrass.

Tolerance: Tolerates pH of 4.0 to 6.9; growth adversely affected above 30 ppt salt.

Establishment: By transplants, tubers, and seed.

Seeds. Store dry at room temperature; seed goes through dormant period. For whatever technique, gentle drawdowns and reflooding recommended to promote growth.

Transplants and tubers. Dig, separate into individual plants and transplant onto site or hold in pots. For tubers, cut off growing shoots (if present) and plant. Top will regenerate.

Value: Good food value for waterfowl and muskrats; shelter for variety of wildlife; muskrats use stems and leaves in lodge construction.

Comments: Often planted to improve waterfowl and wildlife habitat; not adapted to harsh conditions of lower or upper tidal zones. Seldom occurs in pure stands.

Saltmeadow Cordgrass (*Spartina patens*)

Description: Perennial grass in dense meadows; about 0.5 to 1.0 m tall from stolons; stems have weak bases; leaves more than one half the length of the stem and rolled inward; flowers late June to October; seed heads in slender panicles maturing from September to October.

Range: Entire east coast; inland in New York and Michigan.

Habitat: Salt marshes, sandy meadows, and sand dunes; generally from 30 cm below mean sea level to 40 cm above mean high water in silty clays, sands, peats, sandy peat, and organic substrates. Also occurs on higher, drier areas of salt or brackish water marsh as well as on coastal foredunes.

Tolerance: Tolerates pH of 3.7 to 7.9; susceptible to oil and grease contamination, drought; tolerates inundation; prefers salinities of 2 to 12 ppt.

Associated species. Saltgrass in lower areas, marsh elder in upper areas.

Establishment:

Seeds. Collect seed heads, shatter, and store dry at 5°C. Seeds not recommended as propagules.

Transplants. Dig clumps, separate into small lumps, and plant on the site or pot for holding. Since individual plants are very small and many hundreds may be in one clump, individual plant separation is not recommended.

Value: Fair food value for waterfowl; shelter for wildlife; used in dune and marsh stabilization; used as forage crop.

Sea Oxeye (*Borrichia frutescens*)

Description: Woody, 20- to 100-cm tall, multibranched shrub; leaves opposite, fleshy, gray-green, 2 to 10 cm long, often toothed at base, and occurring on stout stems arising from short, creeping rhizomes; flowers yellow in summer, burr-like seed heads in fall.

Range: Gulf and Atlantic coast from Florida to Virginia.

Habitat: High marsh areas, particularly borders of saline and brackish water marshes; generally about 90 cm above mean sea level.

Tolerance: Tolerates pH of 6.1 to 8.0; salinity of 0-25 ppt.

Associated species: Saltmeadow cordgrass.

Establishment: By underground rhizomes or, less often, by seed.

Seeds. Harvest seed heads mid-September to early October, store wet or dry in fresh or 10 ppt saline solution for up to 180 days. Seeds do not go through dormant period; germinate readily any time after harvest, particularly at 10 to 25°C. Forms dense stands.

Transplants. Dig rhizomes supporting vigorous plants and divide; replant in similar habitat no more than 5 to 10 cm deep.

Value: Little wildlife food value. Used infrequently by nesting birds, especially colonial ground nesters. Stabilizes soils near shores.

Slough Sedge (*Carex obnupta*)

Description: Perennial sedge from rhizomes; forms dense stands 30 to 100 or 150 cm tall; stems stiff; seed heads upright.

Range: Pacific Northwest, from British Columbia to California.

Habitat: Fresh to brackish marshes and wet meadows; adapted to low areas with frequent flooding.

Tolerance: pH ranges from 5.5 to 8.0; is not tolerant of mid to high salinities.

Associated species: Seaside arrowgrass, tufted hairgrass, Lyngbye's sedge.

Establishment: By seed or transplants.

Seeds. Hand collect when mature (July to September), store dry or, preferably, in distilled water up to 180 days; no period of dormancy, germinates at 10 to 25°C. Seed propagation not very successful.

Transplants. Dig plant clumps and rhizomes and divide, replanting at depths of 5 to 10 cm.

Value: Various plant parts eaten by many species of wildlife, especially songbirds, dabbling ducks, rodents, and browsing mammals. Valuable cover for wildlife, nesting cover for ducks and geese.

Smartweed (*Polygonum* spp.)

Description: Perennials or annuals; stems many-jointed; leaves narrow and willow-like, swollen leaf nodes; flowers in spikes at end of stalk.

Range: Throughout U. S.

Habitat: Wet soils and freshwater marshes.

Establishment: By transplants, rootstock, seed, cuttings.

Seeds. Seeds should be harvested from August to October and stored dry at 5°C. Broadcast seeds in spring and summer.

Transplants, rootstock, cuttings. Dig whole or portions of plants including any portion of the root system. If planted in any moist area and covered with a light layer of soil, cuttings and rootstock will regenerate and grow. Transplants survive quite well if moved when they are small.

Value: High food value for songbirds and waterfowl. Foliage of some inedible to browsers as it has a hot, peppery taste. Good brood cover in shallow marshes for waterfowl.

Comments: Smartweeds are highly adaptable plants, and may occur in dry soils as well as standing water depending upon the species. They may become pests if allowed to spread to agronomic and pastoral situations.

Smooth Cordgrass (*Spartina alterniflora*)

Description: Perennial salt marsh grass from fibrous rhizomes; stems erect, generally winter-killed, and nearly 2 m high in tall form; leaves alternating and relatively wide (0.4 to 1.5 cm); flowers in midsummer in spikes up to 0.5 m long; seeds ripen late summer and early fall.

Range: Entire east coast; spreading on west coast from place of introduction in Pacific County, Washington.

Habitat: Shallow water of coastal salt marshes from mean sea level to about mean high water in broad range of substrates. Tall form restricted to margins of creeks, natural channels, and areas subject to daily tidal flooding; short form occupies higher levels of marsh near upper limit of tidal influence.

Tolerance: Tolerates pH of 4.5 to 8.5; optimal salinity 10 to 20 ppt, maximum salinity 50 to 60 ppt; withstands storms and saltwater inundation up to 12 hr per day; susceptible to oil and grease contamination.

Associated species: None can compete in its harsh habitat except at the upper tidal limits of its growth range.

Establishment: By transplants, seedlings, and seed. With transplants, one can plant year-round but early to late spring is best.

Seeds. Harvest mature seed in the fall and store wet in estuarine water at 1 to 3°C for up to 180 days. Seeds go through dormant period.

Transplants. Dig young plants from the natural marsh. Plant on the site or pot for holding.

Seedlings. Germinate seeds in peat pots containing marsh soil and a mixture of sand and peat. Plant seedlings onto site in 3 to 6 months or before they become too big for the pots.

Value: Fair food value for waterfowl; useful for substrate stabilization.

Comments: Can be used for direct seeding of marsh sites providing possible dormancy in fresh harvested seeds can be overcome. Severe wave action will destroy stands of this species, but it tolerates normal tidal actions. Heavy grazing by waterfowl can kill young stands.

Soft Rush (*Juncus effusus*)

Description: Perennial rush in thick clumps 0.9 to 1.8 m tall, from short stout rhizomes that creep and spread rapidly; leaves small, reduced mostly to sheathing scales; culms pale green, round in cross-section, ridged, about 0.5 to 5 mm thick, and relatively easy to compress; flowers July to September in pale brown clusters located laterally about 8 to 15 cm from stem tips.

Range: Throughout North America.

Habitat: Freshwater peaty swamps, bogs, and marshy areas; areas that maintain a few inches of water for prolonged periods, such as pools and waterways.

Associated species: Smartweeds, sedges, nutsedge, cattails, rushes, and bulrushes.

Tolerance: Tolerates pH of 4.0 to 5.9 and oil and grease contamination. Tolerates lack of inundation throughout the summer months very well.

Establishment:

Seeds. Gather seeds and store in fresh water at 5°C.

Transplants. Dig clumps and separate into sections for transplanting on the site or into peat pots for holding.

Value: Shelter for wildlife, particularly ducks; food for muskrats, small rodents, and moose; seeds eaten by songbirds; spawning habitat for sunfish; of value in nitrogen fixing.

Comments: Regenerates quickly; harbors mosquitoes, troublesome in Puget Sound and in low pasture areas throughout the U. S. Not palatable to most browsers.

Softstem Bulrush (*Scirpus validus*)

Description: Perennial sedge, about 3 m tall, from stout, scaly, rhizomous rootstock; stems round, tapering, erect, and densely clumped, leaves inconspicuous; flowers June to September; seed head many clusters with small, dark mucilagenous seeds with hard impervious seed coats.

Range: Widespread throughout U. S.

Habitat: Lower areas of freshwater and slightly brackish marshes; also in shallow ponds, log holes, and stream banks; grows in clays, heavy sands, and marls; prefers low water levels.

Tolerance: Tolerates pH of 5.3 to 7.8; cannot tolerate prolonged inundation or even moderately brackish water.

Associated species: Arrow arum, arrowheads, and pickerelweed.

Establishment:

Seeds. Harvest mature seed from July to September, shatter, and store dry or in freshwater. Very difficult to germinate.

Transplants. Dig plants, separate individual plants and replant or pot for holding.

Rootstock. Dig plants and rhizomes; cut off shoots if present; divide individual pieces of plant material taking care to have at least one viable growth point on each piece; plant on site or in pots for holding.

Value: High food value for muskrats, ducks, and other waterfowl; shelter and nesting for various wildlife; useful in substrate stabilization and building new land.

Switch Grass (*Panicum virgatum*)

Description: Perennial grass, 1 to 2 m tall, in large bunches from scaly, creeping, vigorous rhizomes; stems partially woody; leaves long, narrow, and characteristically have a small nest of hair where the leaf blade attaches to the sheath; flowers July to September; large seed produced in abundance in open, delicately branched seed head.

Range: Interior plains, Ontario, Nova Scotia, and Maine to Florida.

Habitat: Open areas on dry to moist sandy soils and shores; upper portions of fresh and brackish water marshes.

Tolerance: Tolerates pH of 4.5 to 7.5; wide range of soil and climatic conditions.

Associated species: Foxtail and groundsel tree.

Establishment:

Seeds. Collect when mature but before shattering and store dry at 5°C. Broadcast planting and raking into soil shallowly is sufficient.

Transplants. Dig clumps, divide into sections, and transplant to site or into peat pots for holding.

Torpedo Grass (*Panicum repens*)

Description: Perennial grass to 1 m from small rhizomes; leaves flat or folded, alternate, and narrow.

Range: Gulf and south Atlantic coasts.

Habitat: Freshwater marshes, estuarine areas and swampy areas; low wet sites but sometimes in submergent situations as well as on high dunes. Grows most rapidly and extensively along ditches, canal banks, and very moist sites; may extend into water and develop large floating mats.

Tolerance: Tolerates pH range of 5.0 to 8.0; wide range of soil and moisture conditions.

Establishment: By transplants or rhizome sections, preferably in late winter to early spring. Dig clumps and rhizomes or pull out of water, divide, and replant or put in peat pots for holding.

Value: Low food value for wildlife; high cover value for wood duck young and waterbirds.

Comments: Effective and rapid stabilizer, but potential nuisance; frequently colonizes portions of dredged material disposal banks; forms pure stands along low sandy beaches.

Tufted Hairgrass (*Deschampsia caespitosa*)

Description: Perennial grass forming densely tangled clumps 60 to 120 cm tall; leaves flat or folded; flowers May to June; seeds mature July to September in purple-tinged seed heads.

Range: Alaska to Greenland and south to New Jersey; West Virginia, North Carolina, Illinois, North Dakota, New Mexico, and California.

Habitat: Fresh to brackish wet places; marsh edges, wet meadows, mountain meadows.

Tolerance: Does not tolerate long periods of inundation or much salinity.

Associated species: Lyngbye's sedge, rushes, and bulrushes.

Establishment: By seed or transplants (either peat-potted or dug from natural stands).

Seeds. Gather, shatter, and store dry or in fresh or distilled water for 180 days; germinate readily at 10 to 25°C.

Transplants. Dig clumps, separate into small sections and transplant immediately into the site or into peat pots for storage.

Value: Excellent forage, provides good wildlife cover.

Comments: Adapted to high marshes; best used in fresh to brackish areas with minimum periods of prolonged inundation.

Water Plantain (*Alisma plantago-aquatica*)

Description: Perennial herb from a corm-like rootstock; leaves basal, elongate, petiolate, narrowly egg-shaped above, floating or emersed on erect stems; flowers small, white, borne on panicles throughout the summer.

Range: Common throughout much of the United States.

Habitat: Shallow, fresh water (up to about 15 cm deep) and wet soils; marshes, ponds, streams, ditches, and lake margins.

Tolerance: Tolerates periods of submergence, turbidity, moderate pollution, and pH of 7.0 to 8.8.

Associated species: Most shallow water emergent fresh marsh species.

Establishment: By rootstock and seeds. The rootstock generally is divided and replanted at same depth in soil and/or water as originally located. Seeds go through period of dormancy. Germination stimulated by water drawdown and light.

Value: Low wildlife value; small quantities of seeds eaten by ducks, a few songbirds, pheasants, and rodents, and the leaves are eaten to a minor extent by rabbits and deer.

Wild Rice (*Zizania aquatica*)

Description: Annual aquatic grass about 1 to 3 m tall; underground roots short, prop roots from lower stem nodes; leaves flat and sheathed, up to 5 cm wide and 100 cm long; flowers July to August in loose purplish clusters on large terminal panicles.

Range: Manitoba to Nova Scotia and throughout eastern half of U. S.

Habitat: Fresh to slightly brackish marshes and slow streams in 5 to 80 cm of water; requires soft, deep mud and slowly circulating water.

Tolerance: Tolerates pH of 6.2 to 8.8; withstands water depths up to 1.0 m and salinities no greater than 2 to 3 ppt.

Establishment:

Seeds. Store seeds wet at 1 to 3°C; seeds do not go through dormant period. Broadcast in fall or early spring; germination requires stable water levels.

Value: High food value for birds and other wildlife, cover for birds.

Comments: Very sensitive to environmental conditions.

Yellow Flag (*Iris versicolor*)

Description: Perennial from pink-fleshed rhizomes; leaves sword-like to 80 cm long; flowers yellow, large, and showy from June to August.

Range: Northeastern quarter of U. S.; less frequently in southeast and Texas.

Habitat: Shallow freshwater marshes and swamps; muddy margins of streams, lakes, and ponds.

Tolerance: Will not tolerate long inundations.

Establishment: By dividing and planting rhizomes as with commercial hybrid iris varieties. Plant shallowly (no more than 2 cm from the top of the rhizome). The rhizomes may even by broadcast on the site and they will take root, but not as successfully as if they were planted individually.

Value: Leaves and stems of some food value to beavers.

Comments: Showy flowers.

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In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

United States. Waterways Experiment Station, Vicksburg, Miss.

Wetland habitat development with dredged material engineering and plant propagation. Vicksburg, Miss. : Environmental Laboratory, Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

107, [51] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; DS-78-16)

Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C.

References: p.97-107.

1. Construction costs. 2. Dredged material. 3. Dredged material disposal. 4. Dredging. 5. Environmental engineering. 6. Marsh development. 7. Plants (Botany). 8. Waste disposal sites. 9. Wetlands. I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; DS-78-16.

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