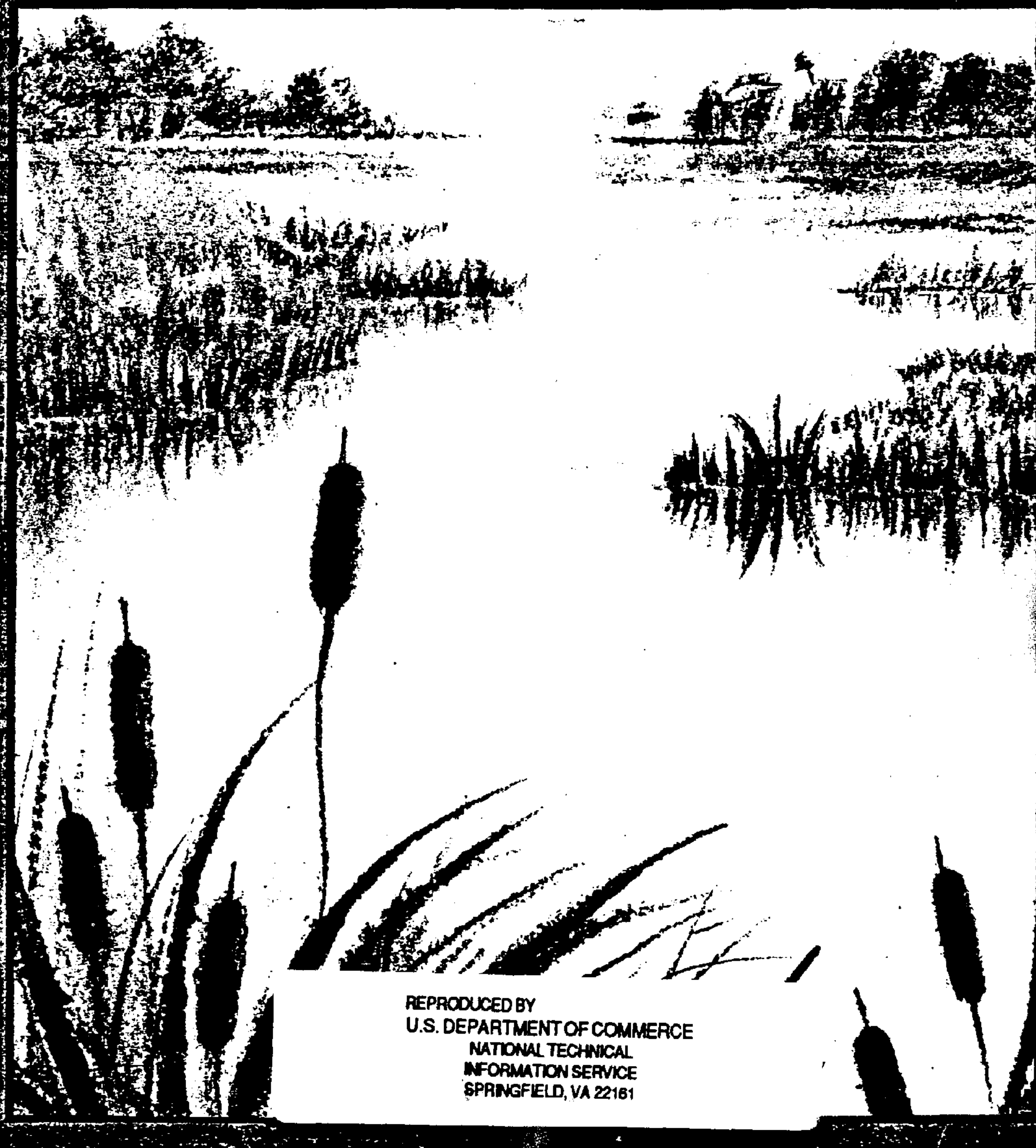
HIGHWAYS AND WETLANDS: COMPENSATING WETLAND LOSSES

U.S. Department
of Transportation
Federal Highway



FOREWORD

The manual is a practical guide for the creation and restoration of wetlands. It provides concepts, methods and general specifications to personnel of State highway agencies for compensating unavoidable wetland losses arising from highway projects. The manual contains information on mitigation and detailed procedures, techniques, and specifications for wetland construction and rehabilitation.

Research, development and implementation of environmental considerations are included in the Federally Coordinated Program under Project 3B, "Environmental Management."

The manual is the final product of an implementation project conducted by the Federal Highway Administration to assist highway personnel in achieving policy goals of Federal and State statutes and regulations pertaining to the Nation's wetlands.

Additional copies of the report can be obtained from the National Technical Information Service, Springfield, Virginia 22161.

R. J. Betsold
Director, Office of Implementation

NOTICE

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16. Abstract

This Implementation Package is a practical guide for the creation and restoration of wetlands. It provides concepts, methods and general specifications for compensating unavoidable wetland losses in a cost effective manner. The manual includes guidance for wetland establishment and enhancement and provides information for the conceptual design of wetland systems.

The site-specific nature of wetland compensation measures precludes giving detailed instructions and specifications for the establishment and enhancement of wetlands. Although much work on the establishment of wetlands has been published within the past decade (Appendix B), the state-of-the-art is still primitive. Consequently, this manual is far from the last word. It is a beginning and a lot is left to the best judgment of the users.

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HIGHWAYS & WETLANDS

Compensating Wetland Losses

Sponsored by the
U.S. Department of Transportation
Federal Highway Administration
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Washington, D.C.

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Preface

There is probably little of our natural environment that has not been altered. Restoring disturbed natural areas, enhancing existing ones, and creating new ones to replace those that have been lost offer challenges and opportunities for productive and creative work to those concerned with the maintenance of our national resources.

This manual for personnel of state departments of transportation provides concepts, methods, and general specifications for compensating unavoidable wetland losses arising from transportation projects. It is a qualitative and practical guide for wetland establishment and enhancement.

The site-specific nature of wetland compensation measures precludes giving detailed instructions and specifications for the establishment and enhancement of wetlands. Depending upon the qualifications of the in-house staff of users of this manual, varying amounts of outside consultation may be required to develop the final designs for wetland compensation measures. At the minimum, it is hoped that this manual will be useful in the development of conceptual designs, so that coordination with state and federal regulatory agencies can progress without outside consultation and that the requisite wetland permits for transportation projects can be secured expeditiously.

Although much work on the establishment of wetlands has been published within the past decade (see Appendix B), the state-of-the-art is still primitive. Consequently, this manual is far from the last word. It is a beginning and a lot is left to the best judgment of the users.

The section Target Perennial Wetland Plants is the point that the manual becomes more technical. Earlier sections are more conceptual, and the use of graphics is intended to make these sections more readable for non-technical personnel of state departments of transportation. It is hoped that the technical staff will benefit from all sections of the manual.

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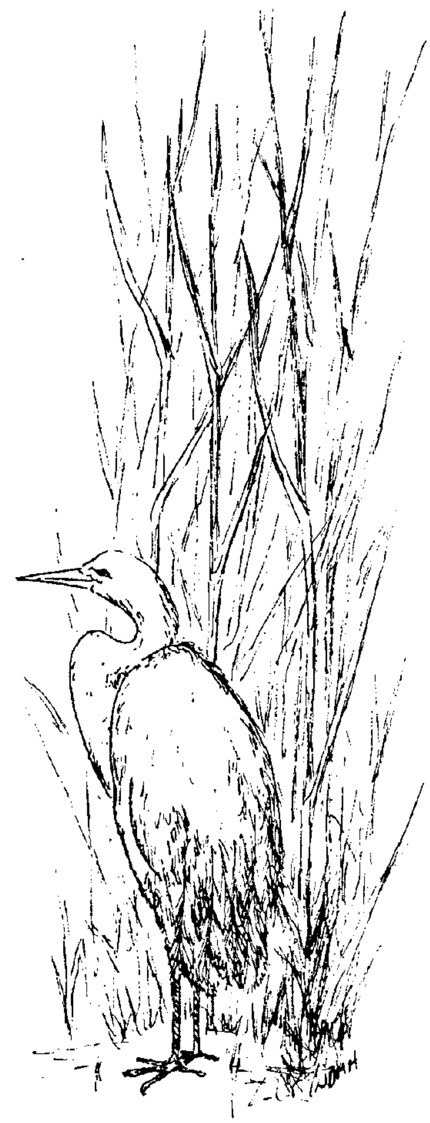

Salt marshes are found in protected bays and throughout the lower reaches of their tributaries. Tidal freshwater marshes often are associated with the upper reaches of these tributaries. Mangrove swamps occupy tidal saltwater areas of southern Florida and Texas and occasionally swamps may occupy tidal freshwater river banks. Swamps, bogs and non-tidal freshwater wetlands mostly are found inland.

1. Introduction

1.1 Wetland Definitions

The U.S. Department of the Interior (DOI), Fish and Wildlife Service, Classification of Wetlands and Deep-Water Habitats of the United States (December, 1979) defines wetlands as lands where water is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface. The definition of wetlands varies in states having specific wetland regulatory programs.

Wetlands also may be defined as lands that are continually, seasonally, or periodically submerged and which support or can support emergent, submergent, or floating aquatic plants. Consequently, many types of land can be considered wetlands. Among these are floodplain and pothole areas. These areas may be dry much of the year and support upland plant species, as well as wetland ones, and occasionally may be cultivated.

Although wetland delineations have been made and legislatively approved in some states, federal agencies make independent case-by-case evaluations of wetland boundaries and areas. Consequently, state and federal wetland delineations may not coincide.

1.2 Wetland Types[1]

Wetland types are characterized by the vegetative communities associated with them. Five broad types of wetlands exist throughout the United States: tidal marshes, non-tidal marshes, swamps, bogs, and submerged grasses. Marshes, swamps, and submerged grasses may exist in both freshwater and saltwater. Generally, marshes are dominated by soft-stemmed herbaceous (non-woody) vegetation, while swamps are characterized by a predominance of woody plants. Bogs are found in poorly drained inland depressions and support acid-tolerant woody and aquatic plants. Submerged grasses often occupy tidal flats and the shallows of lakes, bays, and rivers.

1.3 Wetland Functions and Values

Wetlands are important fish and wildlife habitats. They directly and indirectly supply food to a large array of animals including microorganisms, invertebrates, fish, birds, mammals, and reptiles. Wetlands purify water by filtering out suspended matter and utilizing dissolved nitrogen and phosphorus for plant growth and development. They may provide flood control by storing and detaining storm water. Freshwater wetlands often function as ground water recharge areas. Wetlands also control shore erosion in the more sheltered regions of estuaries, bays, and lakes.

Assigning monetary values to wetland functions is impossible, because no two wetlands function identically, nor are they of equivalent quality. However, proper economic analyses of wetlands on a site-specific level are possible, provided the necessary biological and physical information are available. The problem is that information generally is not available, nor is it easily acquired.

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[1]For the purpose of this manual it is not necessary to describe the new and detailed wetland classification system that may be widely used in the future. This system is discussed in Water Spectrum (Spring, 1980, pp. 17-25) and detailed in Classification of Wetlands and Deep-Water Habitats of the United States (DOI, December 1979).

2. Concepts and Considerations for Compensating Unavoidable Wetland Losses

Dredged spoil disposal area that has limited value for fish and wildlife. The site is near Atlantic City, New Jersey, and was used as the wetlands replacement location to compensate wetlands lost during the construction of an improved water treatment facility.

Unavoidable losses of wetlands can often be offset by appropriate compensation. There are no formulas for compensation. Compensation is largely subjective.

Even in the simplest case, where all lost wetlands can be successfully restored to their original condition after project construction, adequate compensation is not clear. In this instance, the highway project is there, and a successfully restored wetland does not ensure that all the original wetland functions and values have been returned. Additionally, a wetland that is restored was still removed from the system during the construction period, and its functions and values were lost for that time.

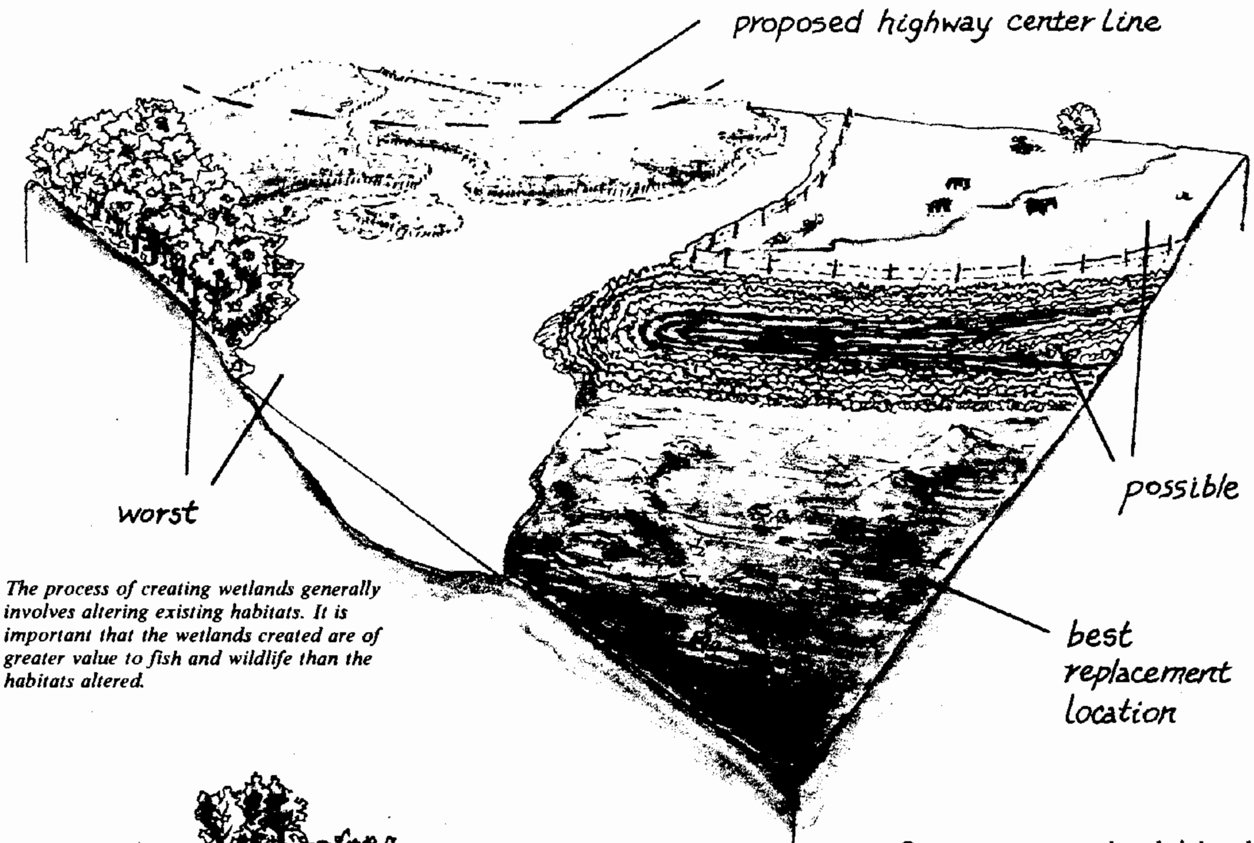
Wetland replacement location after preparing the site for new wetlands.

2.1 Wetland Replacement

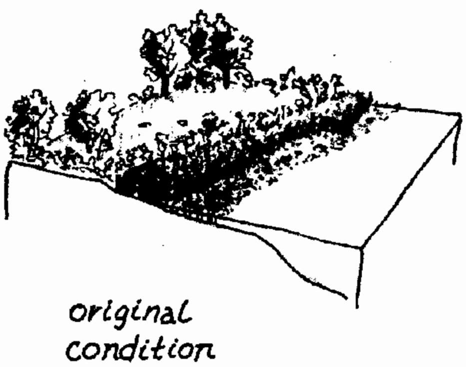
2.1.1 **Replacement Location.** The two principal criteria that must be applied in the selection of lands for conversion to wetlands are:

- The land should have low fish and wildlife resource value in its present state.
- An adequate water supply (river, stream, tidal source, ground) should be available for connection to ensure a successful wetlands development.

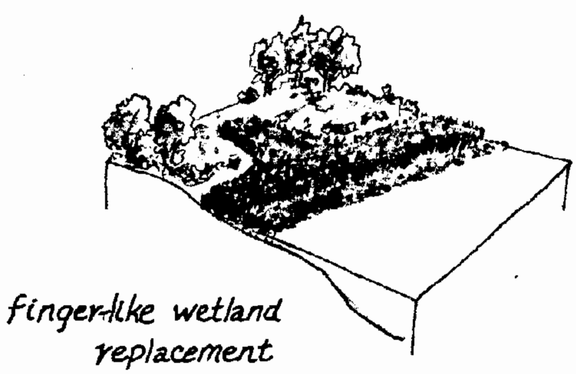
New wetlands 10 months after installation of the wetland plant materials.

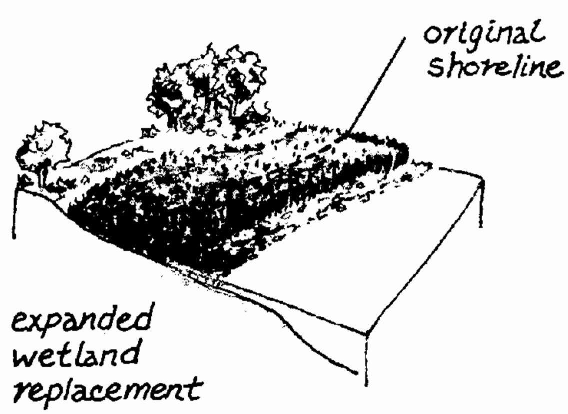


The process of creating wetlands generally involves altering existing habitats. It is important that the wetlands created are of greater value to fish and wildlife than the habitats altered.



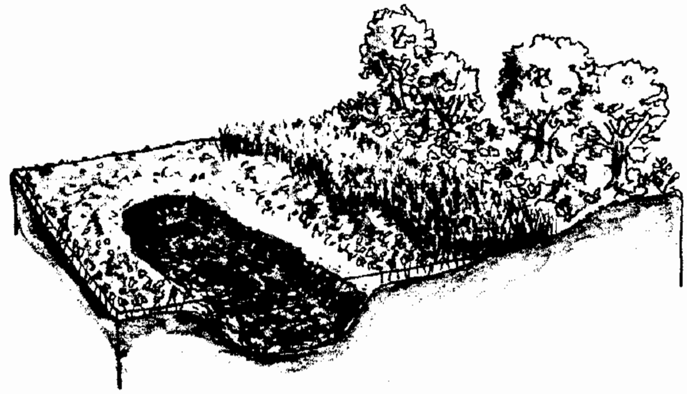
Open water, upland islands interspersed throughout wetlands and mature forested areas are poor candidates for wetland replacement locations unless these areas are particularly degraded in value. Locations that would introduce finger-like intrusions into upland areas from wetland ones are discouraged. Such areas are collectors of debris and litter and may have limited potential for exporting organic production unless they are located in drainage areas that are subject to periodic storm water flows.

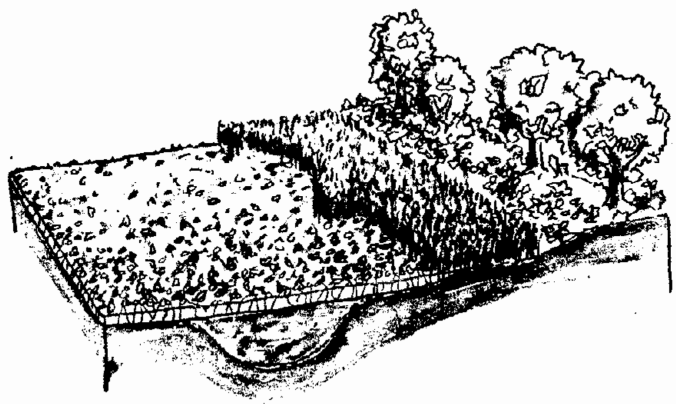




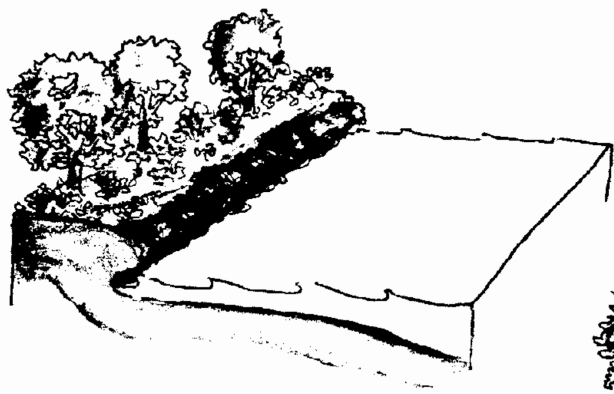
Finger-like intrusions of wetlands into upland areas may collect floating debris and limit organic export. The maintenance of the existing natural shoreline configuration may be a preferable design for wetland replacement.

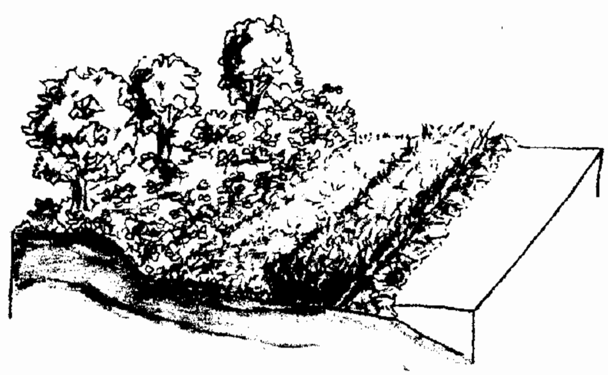
Lands that can expand the existing natural shoreline configuration are preferred to ones that will alter it. Areas in evidence of natural sediment accretion (deposition) are preferred to those exhibiting scouring and erosion. Inland and aquatic deep water holes derived from dredging, mining, or borrow operations, may become or already are chemically and biologically degraded and are potential wetland replacement locations. Unvegetated and/or disturbed shorelines are important candidates for fringe wetland replacement of small areas, although breakwater protective structures may be required for wetland stability.





Deep holes in aquatic habitats may be environmentally degraded and may have potential for wetland replacement areas.



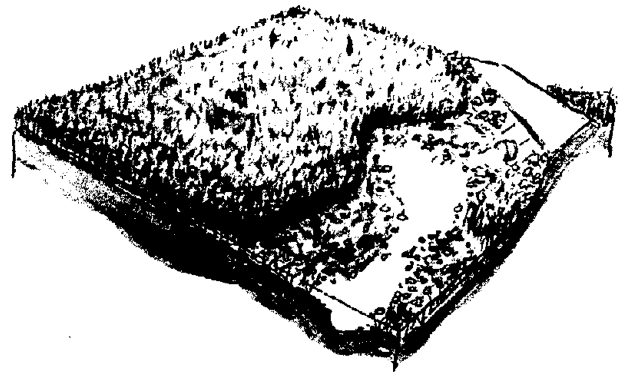


Stabilizing unvegetated shores through wetland establishment provides erosion control and a productive biological edge to upland areas.

An unvegetated and eroding shore in mid-Chesapeake Bay, MD.

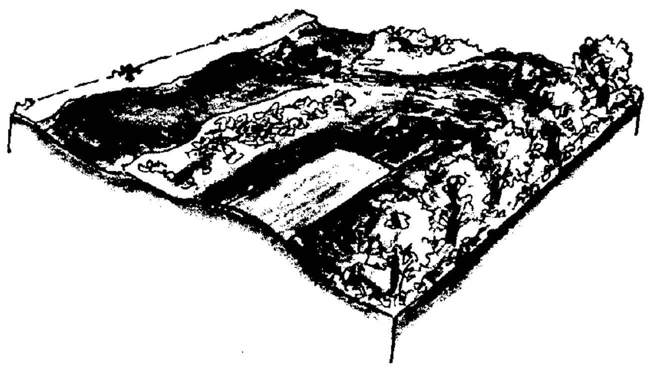
View of the shore three months after installing the wetland plant materials.

Abandoned dredged material disposal areas may qualify as acceptable wetland replacement sites.

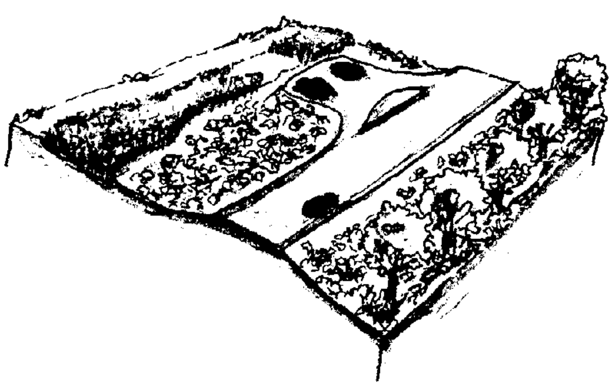


Inactive dredged material disposal sites of poor wildlife value should be considered for wetland replacement areas. The disposal materials may be acceptable for highway construction purposes and the excavated area may qualify as a suitable location for wetland replacement.

Borrow areas and surface water control structures that may be required for the highway project have potential to be economically designed as acceptable wetland replacement locations. Such areas may be multifunctional, providing highway storm water management, scenic, recreational, and fish and wildlife functions.



Borrow areas used for highway construction may be designed for wetland replacement locations.

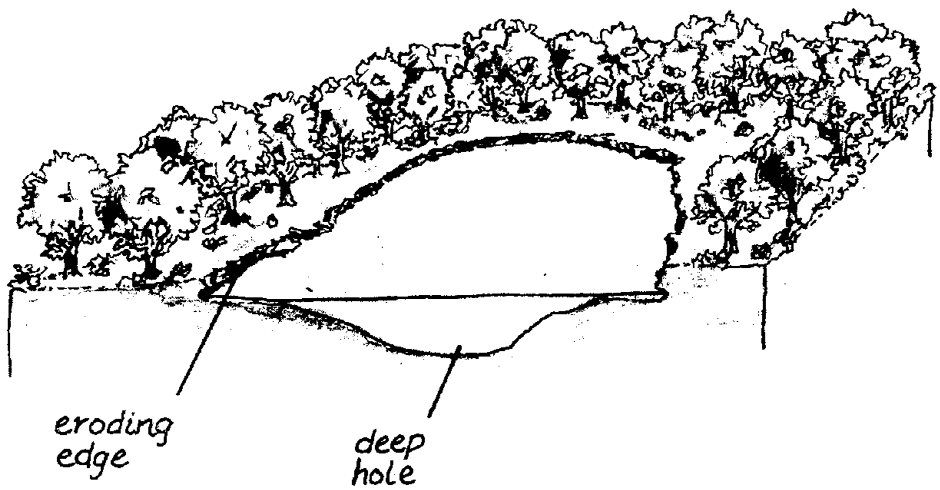


The junction of two habitat types often provides a zone (ecotone) with a more diverse biological community than either habitat taken alone (the edge effect). Consequently, a wetland replacement location that offers the opportunity to develop the greatest lineal footage of new edge should be explored.

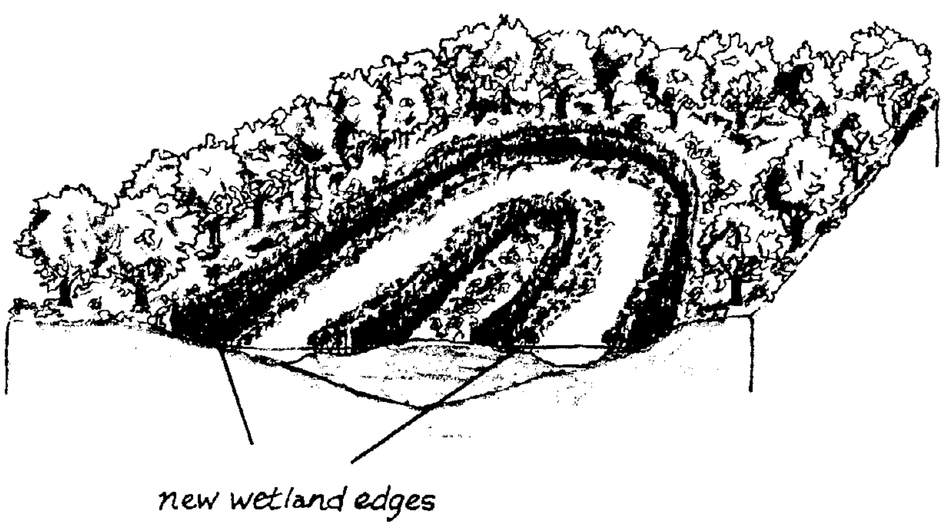
Consideration of alternative locations for wetland replacement should be coordinated with the regulatory consulting resource agencies. Assistance from these agencies should be encouraged.

2.1.2 **Wetland Replacement Type.** The replaced wetland should not necessarily be of the same type as that which was lost. Often providing a wetland type that is different from that which was lost may offer improvements for fish and wildlife or for the control of water quality, flooding, and shore erosion. In considering the type of wetland to be replaced priority should be given to types that:

- can be rapidly established
- render the most important functions to fish and wildlife
- will not rapidly evolve into uplands.

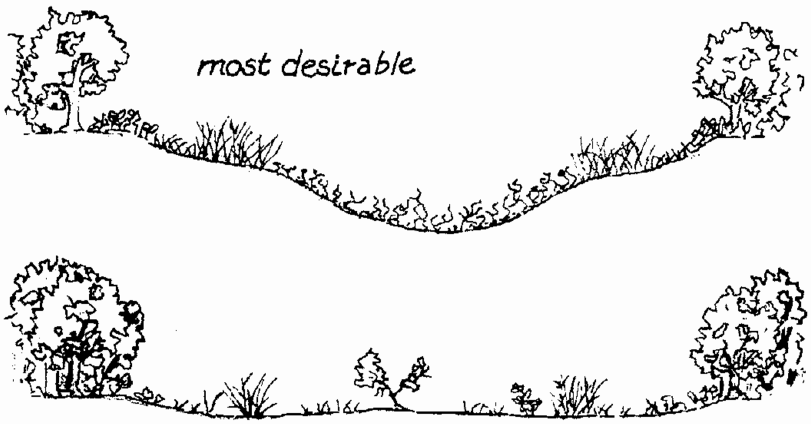


Creating the maximum lineal footage of wetland edge is ecologically attractive.

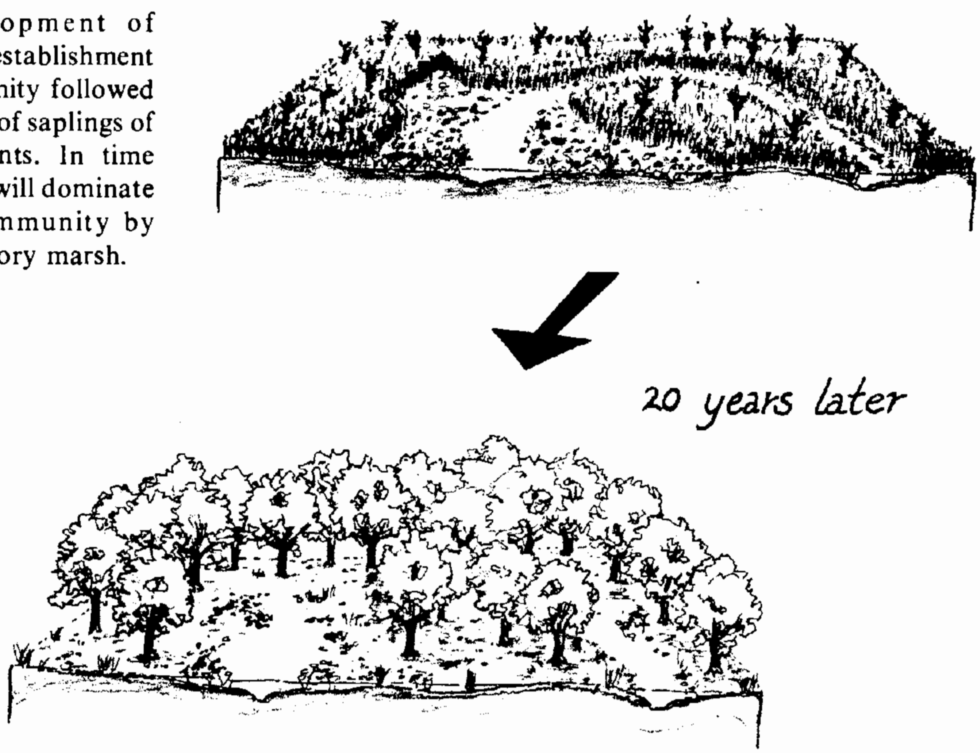


Wooded wetlands (swamps) cannot be rapidly established because trees require years to mature. High elevation or intermittently flooded wetlands have little value to fish and are likely to evolve into uplands. Consequently, the best types of replacement wetlands are intertidal and low elevation marshes—wetlands that are periodically inundated by tides and ones that are permanently flooded by shallow water. Plants typically associated with these wetland types are emergent and herbaceous.

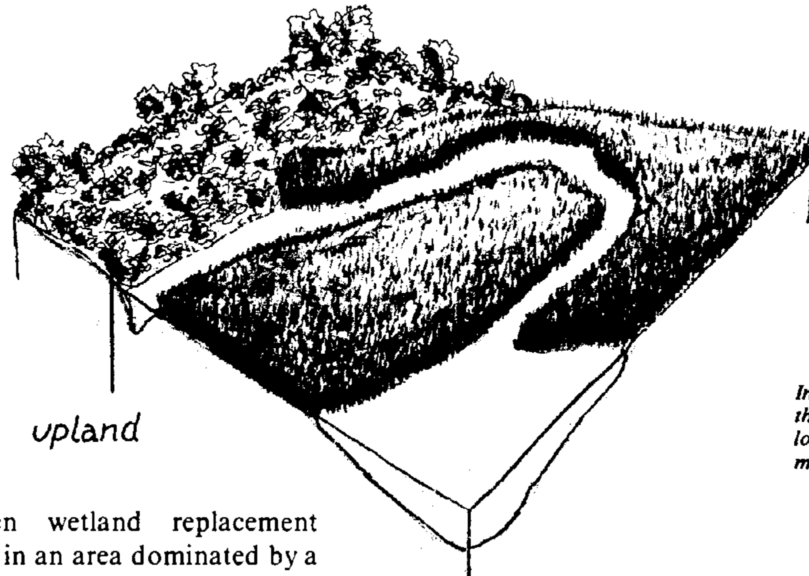
Little information is available on the establishment of bogs. Submerged grass wetland types qualify as priority wetland replacement types; however, their successful establishment is more sensitive to physical (turbidity and temperature) parameters of the water than are marsh (emergent) wetland types. Consideration might be given to the long-term development of swamps by initial establishment of a marsh community followed by the introduction of saplings of desired woody plants. In time these woody plants will dominate the vegetative community by shading the understory marsh.



Regularly or permanently flooded wetlands have the greatest longevity and the greatest values to fisheries and water quality control.

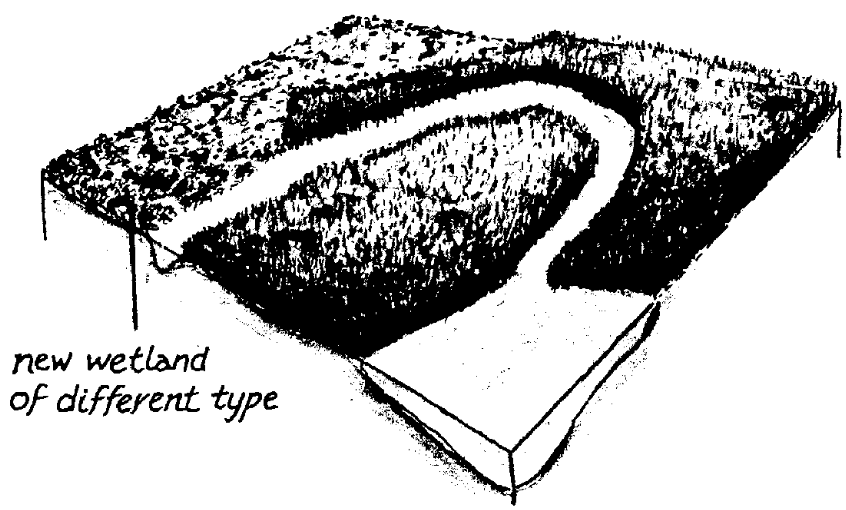


Swamps may be best established by the initial development of a marsh to provide rapid substrate stability and habitat values to fish and wildlife. Saplings of the desired woody swamp plants then may be interspersed throughout.

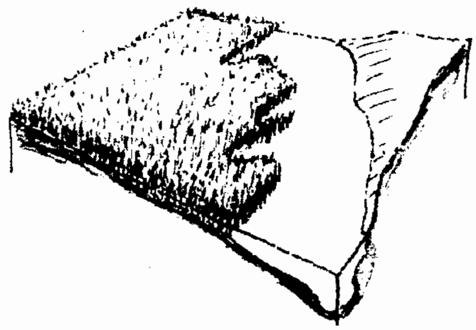


Introducing new wetlands of a different type than exists about a wetland replacement location will provide diversification which may benefit fish and wildlife.

When wetland replacement occurs in an area dominated by a single or a few wetland species, thought should be given to the feasibility of creating a wetland consisting of different wetland species. The introduced species and the resulting habitat diversification could lead to combined wetland values and functions that are greater than those offered by the existing wetland.



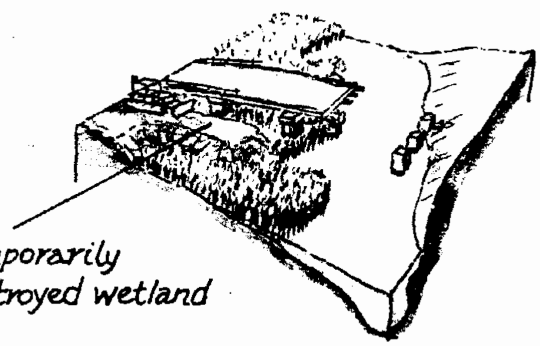
The final selection of a wetland replacement type should not be made until the regulatory and consulting resource agencies have had an opportunity to review the alternative types and to express their opinions.

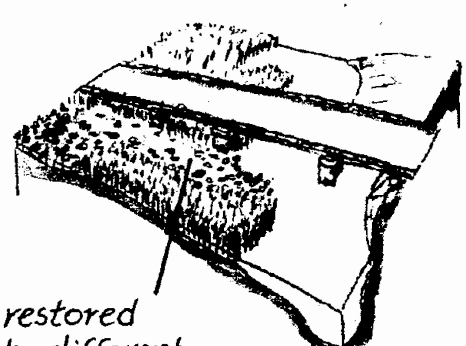


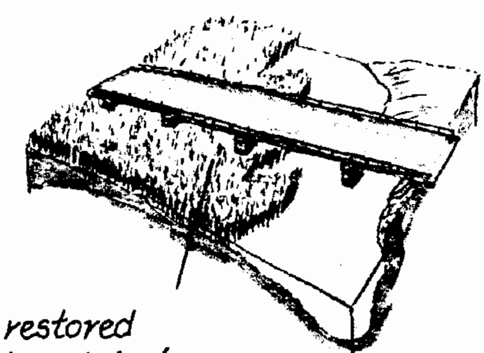
2.2 Wetland Restoration

In order for the contractor to perform the work, the construction of a highway in wetlands may require temporary dredged channels, earthen causeways, staging areas, and turn-around areas. The construction of these work areas may unavoidably disturb or destroy wetlands. Restoration of these areas to their original condition, following completion of the highway project, should be part of the mitigation plan.

When restoration is required, consideration should be given to replacing the wetland temporarily lost with another wetland type that will lead to an enhancement in functions of the wetland system in the area or that will be of greater value than the original wetland in terms of operating functions (see Wetland Replacement Type).



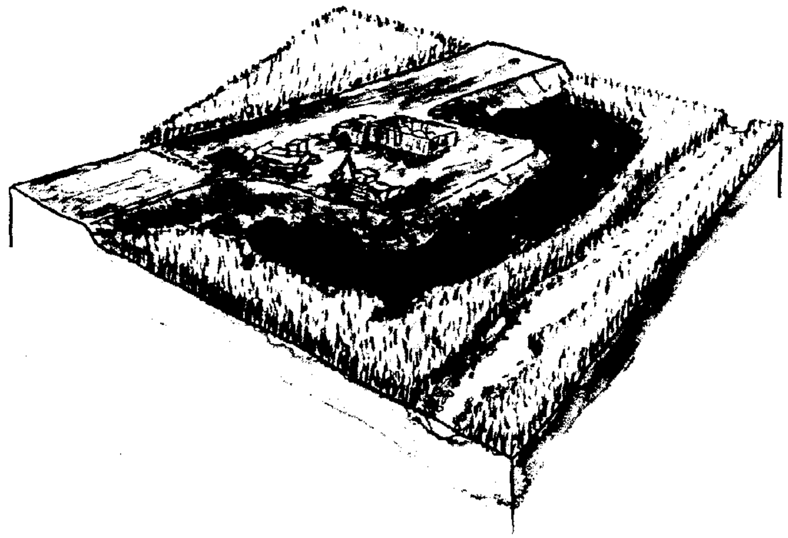




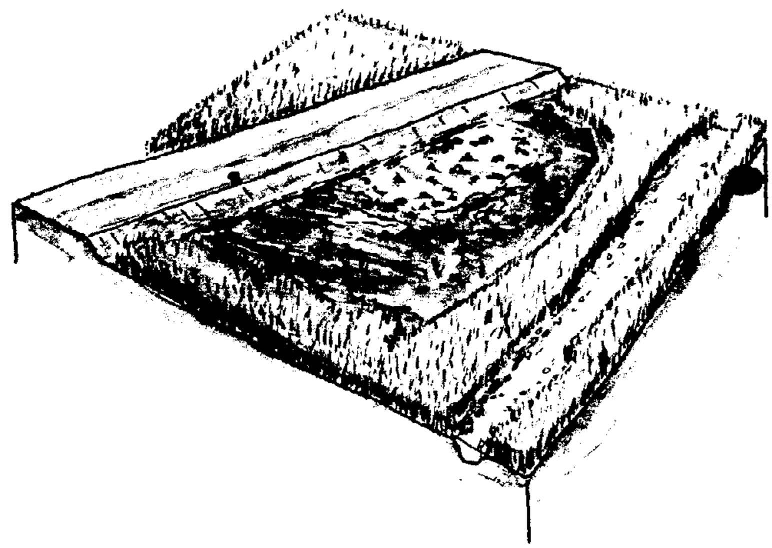
Wetland restoration can be accomplished with or without enhancement features. One enhancement feature that might be considered is diversification—the replacement of the wetland temporarily destroyed by a different wetland type than pre-existed and than exists in the immediate area.

View of a wetland area (Tuckerton, NJ) that was previously destroyed by a construction causeway. The contiguous wetlands are high elevation salt marshes. The restoration design lowered the final grade relative to the pre-existing one to permit regular tidal inundation and to permit the establishment of a tidal salt marsh (Spartina alterniflora). This design provided improvements in vegetative diversity, drainage of contiguous wetlands (mosquito control), and habitat values to fish and wildlife. Photograph was taken two months after installation of the wetland plant materials.

View of the site 10 months after installation of the wetland plant materials.



Stockpiling excavated wetland materials on contiguous wetlands may suffocate the wetlands stockpiled upon. The stockpiled wetland materials may lose their biological viability upon storage or during the resurfacing and grading operations. Grading excavated wetland materials to provide an acceptable well-drained final grade is difficult to accomplish.

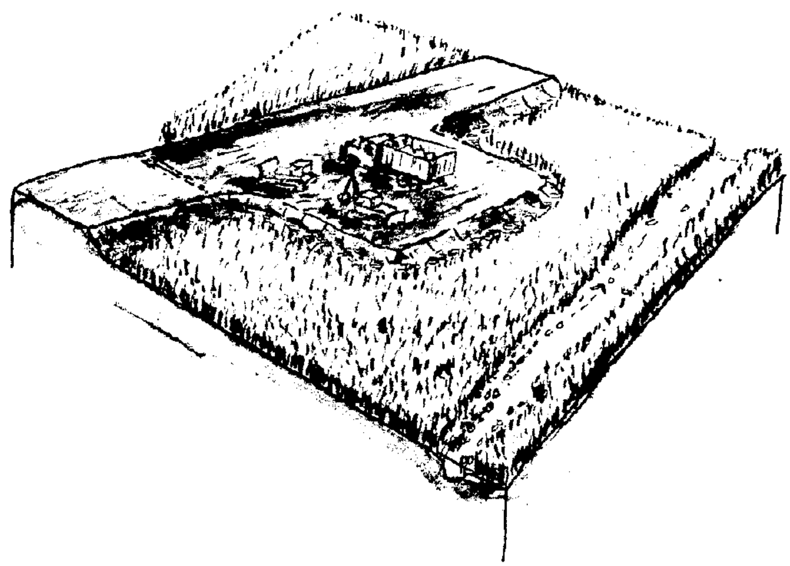


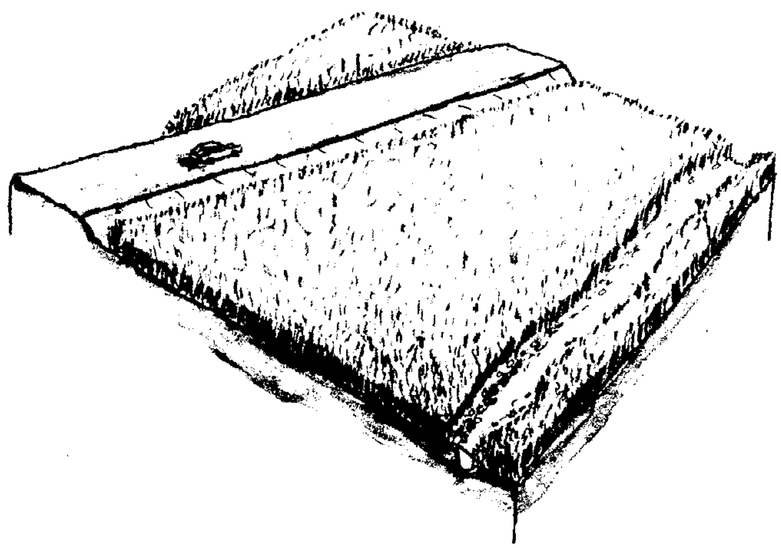
2.2.1 **Stockpiling Wetland Materials for Restoration.** Some projects require dredging that may destroy or disturb wetlands. For these projects and for those that may require filling in wetlands, it is often questioned whether the surface wetland materials—those that contain the bulk of the viable plant parts—should be excavated, stockpiled, and maintained for future use. The objective of stockpiling is to maintain viable plant materials that can be used for resurfacing the restoration area.

This approach to restoration has had varied success. Contractor expertise, unavoidable construction delays, and weather conditions will affect the degree of success. The stockpiled wetland materials may deteriorate from freezing, desiccation, decomposition, or salt buildup during storage. Methods to avoid such deterioration are not often available.

Stockpiling on wetlands may lead to the suffocation and loss of these wetlands. Accomplishing the final grade using surface wetland materials may not be possible. Plants are likely to be destroyed during grading and resurfaced areas may be left with scattered peat hummocks (mounds) and pockets of impounded water. Such conditions may prevent successful restoration of the wetland.

To maximize successful restorations and to minimize additional wetland involvements, stockpiling must be confined to upland areas and contract specifications must limit stockpile durations to less than four weeks.



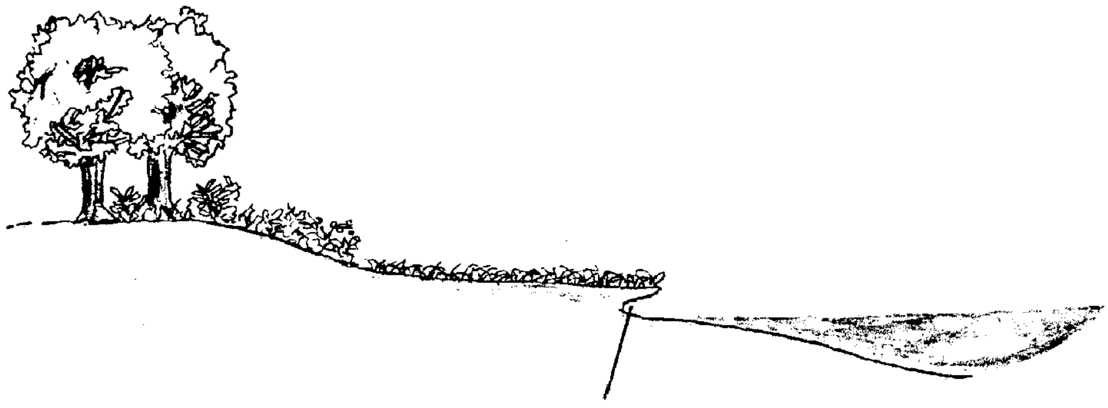


Discarding excavated wetland materials minimizes the wetland area disturbed. Final grading and revegetation of clean inorganic borrow materials are readily accomplished.

2.2.2 **Discarding Wetland Materials.** There is another general approach that has been used to restore wetland areas that have been dredged for the construction of a temporary causeway, staging area, or turn-around area. This approach uses nursery plant materials for revegetation. All dredged wetland materials are discarded in an upland area, and the revegetation operation occurs on the clean inorganic borrow materials that were used to construct the temporary work area.

This approach provides a final restoration area consisting of typical borrow materials (largely sand and gravel). These substrates generally impose no limitations on successful wetland establishment.

This approach is preferred to the stockpiling procedure described previously. Disturbance of the wetland area is kept to a minimum, because there is no stockpiling of excavated materials on wetlands. There are no time restrictions imposed on the project by restoration requirements. Unpredictable project delays and weather conditions normally will not influence the success of restoration. The restoration areas can be easily brought to final grade using conventional equipment. This approach is also less expensive than stockpiling.



2.2.3 **Other Restoration Considerations.** If the wetland is dredged to construct a temporary work channel, either the dredged materials or clean borrow materials may be used to backfill the channel after its use and to return the area to the prescribed grade for restoration.

In such instances, the dredged materials should be stored on an upland site. However, no effort should be made to maintain the viability of the surface wetland materials. The suitability of these dredged materials for use as backfill for the top foot of surface will depend upon (1) their gradability and (2) the extent of possible salt buildup during storage (for salt marsh wetlands). If the dredged materials are unsuitable, clean borrow materials may be used for surfacing the restoration area. Nursery plant materials are used for revegetation.

If a stable temporary causeway, staging area, or turn-around area is constructed by first surfacing the wetland with suitable filter fabric (to distribute the load) followed by adding the requisite borrowed materials, the wetland surface may be expected to compress (sink). The amount of compression will depend upon the final load and the softness of the wetland.

In preparing such areas for restoration, all fill materials, including the filter fabric, should be removed. The borrow materials then may be reused, as required, to bring the area to the required grade for restoration. Nursery plant materials are used for revegetation.

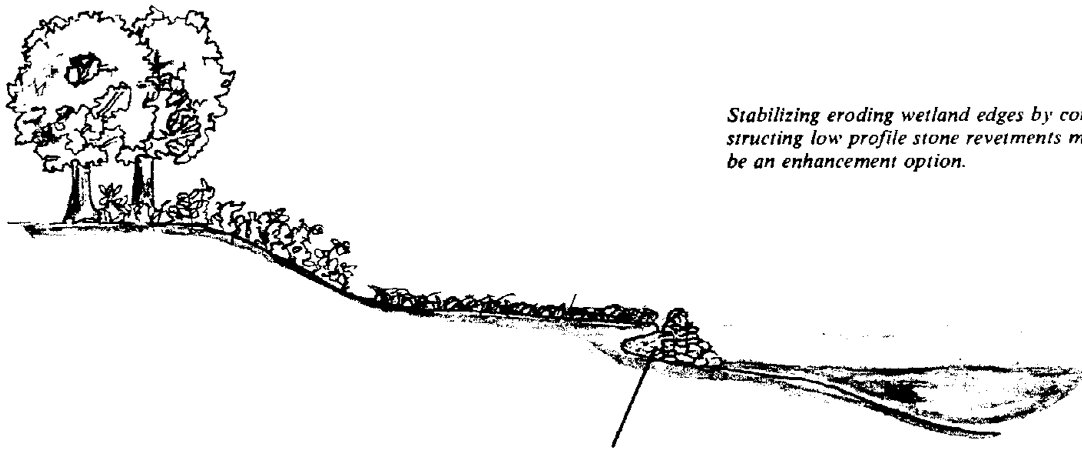
2.3 Enhancement

Enhancement is the improvement of fish and wildlife resource and social values within or beyond the project's right-of-way. In order to be considered favorably by the consulting resource agencies, any enhancement proposal must relate to fish and wildlife. Additionally, in reviewing a mitigation plan for a 404 permit, the Corps of Engineers will accept proposals for the enhancement of social values.

Existing natural wetlands often can be improved to make their potential functions real functions. The enhancement concept offers highway department personnel an opportunity to innovatively incorporate improvements to wetland environments in their highway projects, when wetland involvements are unavoidable. Opportunities for enhancement should be considered as an integral part of any wetland restoration and replacement effort as well as by itself.

Possibilities for wetland enhancement will vary for each wetland considered. No general recipe for enhancement can be provided, although some possible considerations can be outlined. Consultation with the state and federal resource agencies regarding possible enhancement alternatives is encouraged.

2.3.1 **Erosion Control.** Wetlands often are found to be unstable along the water's edge. Wind driven waves, boat wakes, and tidal interaction may undercut and erode the peat banks of unsloped wetland edges. Such instability can be controlled by constructing a low profile stone (riprap) revetment along the face of the peat bank. Such a revetment provides a new environment (an added edge effect) for algae, barnacles, and microflora to live in. Aquatic reptiles and fish may utilize the interstices in the revetment at times of high water.

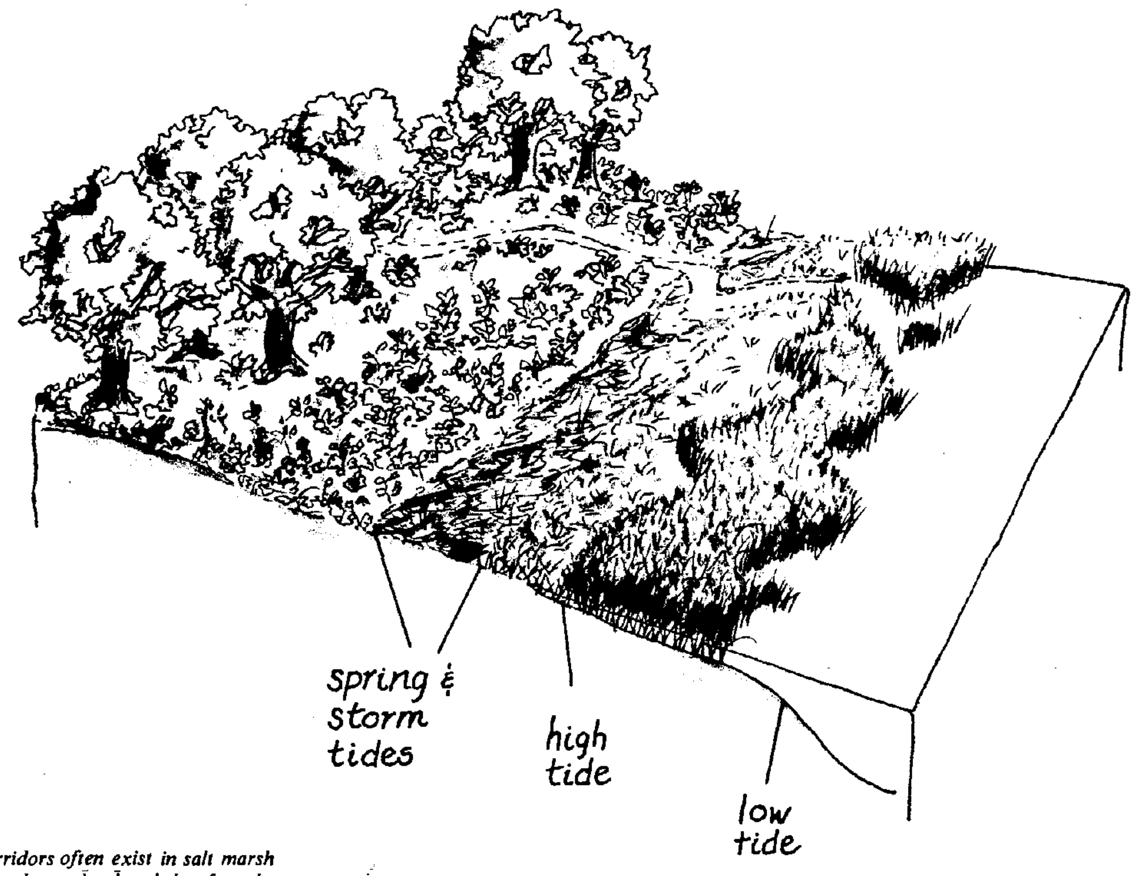


Stabilizing eroding wetland edges by constructing low profile stone revetments may be an enhancement option.

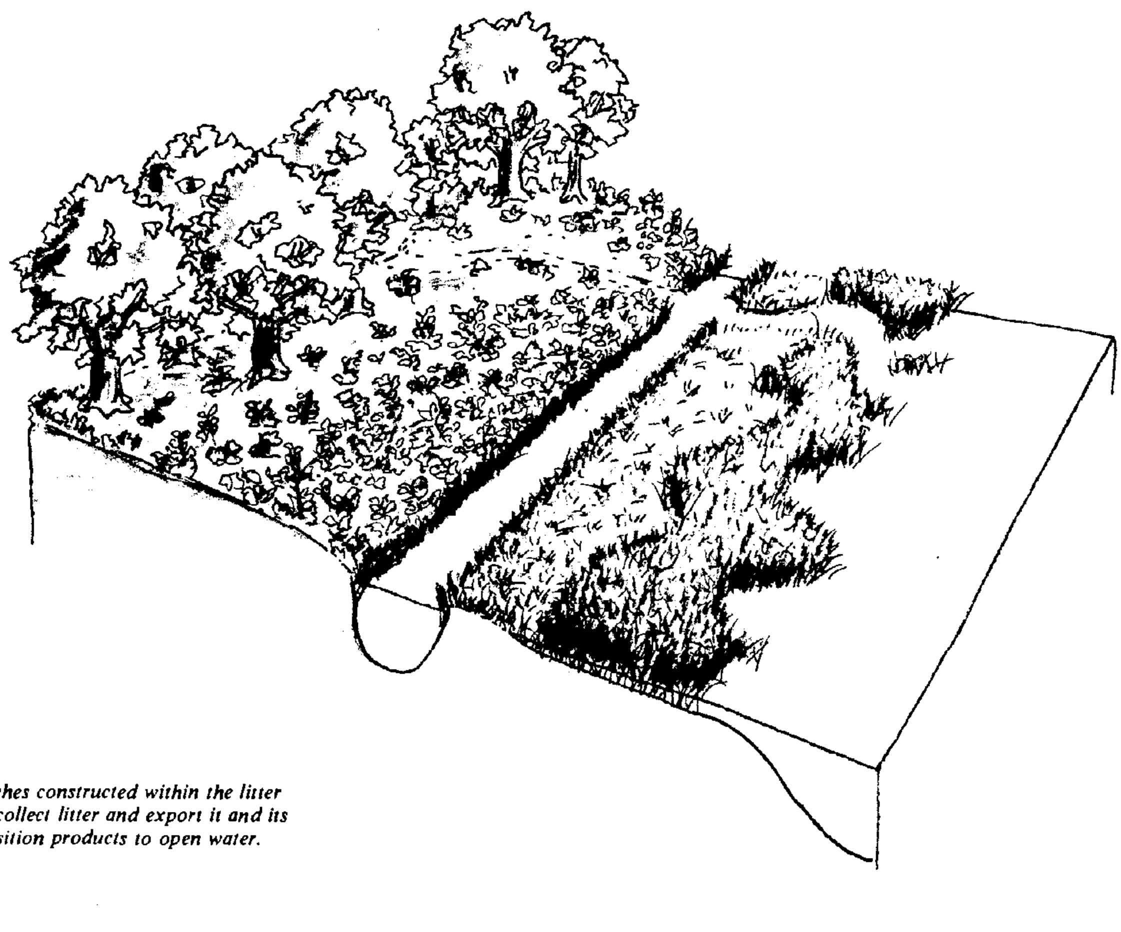
2.3.2 **Litter Corridor Ditching.** Wetlands that are contiguous to upland areas collect litter and debris throughout the zone between normal high tide and storm water tide. Particularly in salt marsh wetlands (in freshwater wetlands the aboveground vegetation decomposes more rapidly and does not tend to collect), the vegetation aboveground is naturally harvested by the elements during the fall and winter months and washed landward. If tidal creeks do not intercept this flow of litter and export it to open water, the litter deposits at the water-land junction. Over time this litter accumulates, smothering the underlying vegetation throughout this zone. This zone is called the litter corridor. Occasionally, an unusual storm will wash the slowly decomposing litter to yet higher elevations, leaving the usual litter corridor as a barren peat flat and creating a new one. Litter corridors most often are found along the upland-wetland edge in salt marsh areas that face the direction of the prevailing winter winds.

The litter corridor often is part of the transition zone between wetland and upland. Occasionally, shrubs that are associated with this transition zone will exclude the import of litter and confine it to lower elevation wetland areas. Although the litter corridor may contain insects and other invertebrates, its overall biological productivity is low compared with that of undisturbed wetlands.

Whether associated with mitigation for the construction of a permanent highway embankment or as an enhancement proposal to mitigate another type of highway involvement of wetlands, construction of litter corridor ditches should be considered, particularly in salt marsh areas. Such ditches are to be constructed in the litter corridor of an existing wetland or the expected litter corridor of a highway project and be connected to open water. They should have bottom elevations below Mean Low Water for tidal areas. The function of these ditches is to collect the washed in litter and export it and its decomposition products to open water for utilization by aquatic animals. The slopes of the ditches additionally will provide a valuable increase in edge effect.

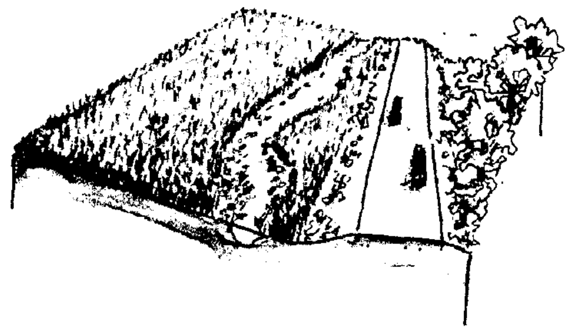


Litter corridors often exist in salt marsh areas that abut upland and that face the prevailing winter winds. These corridors are biologically deprived.



Tidal ditches constructed within the litter corridor collect litter and export it and its decomposition products to open water.

Degraded wetland areas can be restored.



2.3.3 **Altering Degraded Areas.** Wetlands have been used as dumping grounds, dredged spoil disposal areas, recipients of toxic point source discharges, and sites of various expired developments. Although these wetlands may now be biologically degraded, they can be restored to healthy viable systems.

Such degraded wetlands within and beyond the highway right-of-way may be candidates for enhancement measures. These measures normally call for removal of discarded debris, removal of dredged materials to achieve desired wetland elevations, removal of contaminated sediments and replacement with clean ones, and removal of abandoned structures and materials. Following such removal, barren and disturbed areas can be revegetated. If the wetlands surrounding the degraded one lacks vegetative diversity, returning the degraded wetland to a different vegetative community might be a further enhancement feature.

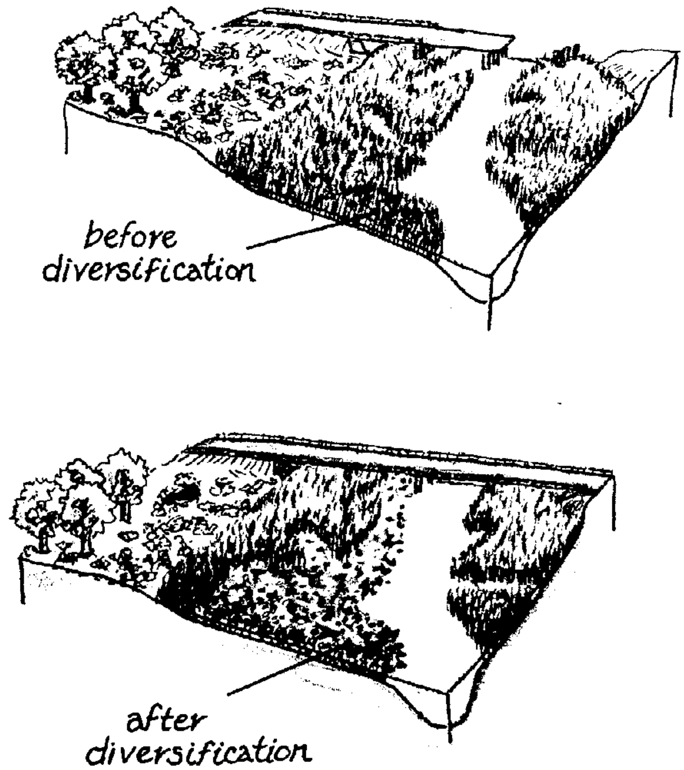
Before proposing to remove dredged materials from a wetland disposal site, the habitat value of the spoil area to wildlife should be reviewed. Even barren, dredged material disposal areas are of potential value to birds for nesting and resting. They may also offer refuge to wildlife during storm water levels and add valuable diversity to the wetland habitat.

2.3.4 **Diversification.** Many wetland types are vegetatively monotypic. Whereas this condition is most common in salt marshes, it is encountered also in brackish and freshwater wetlands. In saltwater areas the condition is attributable to substrate and interacting water salinities and to surface elevations. The origin of this condition in freshwater areas is less certain, but surface elevations, substrate acidity, and antibiosis (one population produces a substance harmful to a competing population) may be contributing factors.

A wetland of low vegetative diversity has a low capacity to support a diverse wildlife population. Nevertheless, such a wetland may possess high values in the support of fisheries, in flood and erosion control, in ground water recharge, and in water quality maintenance.

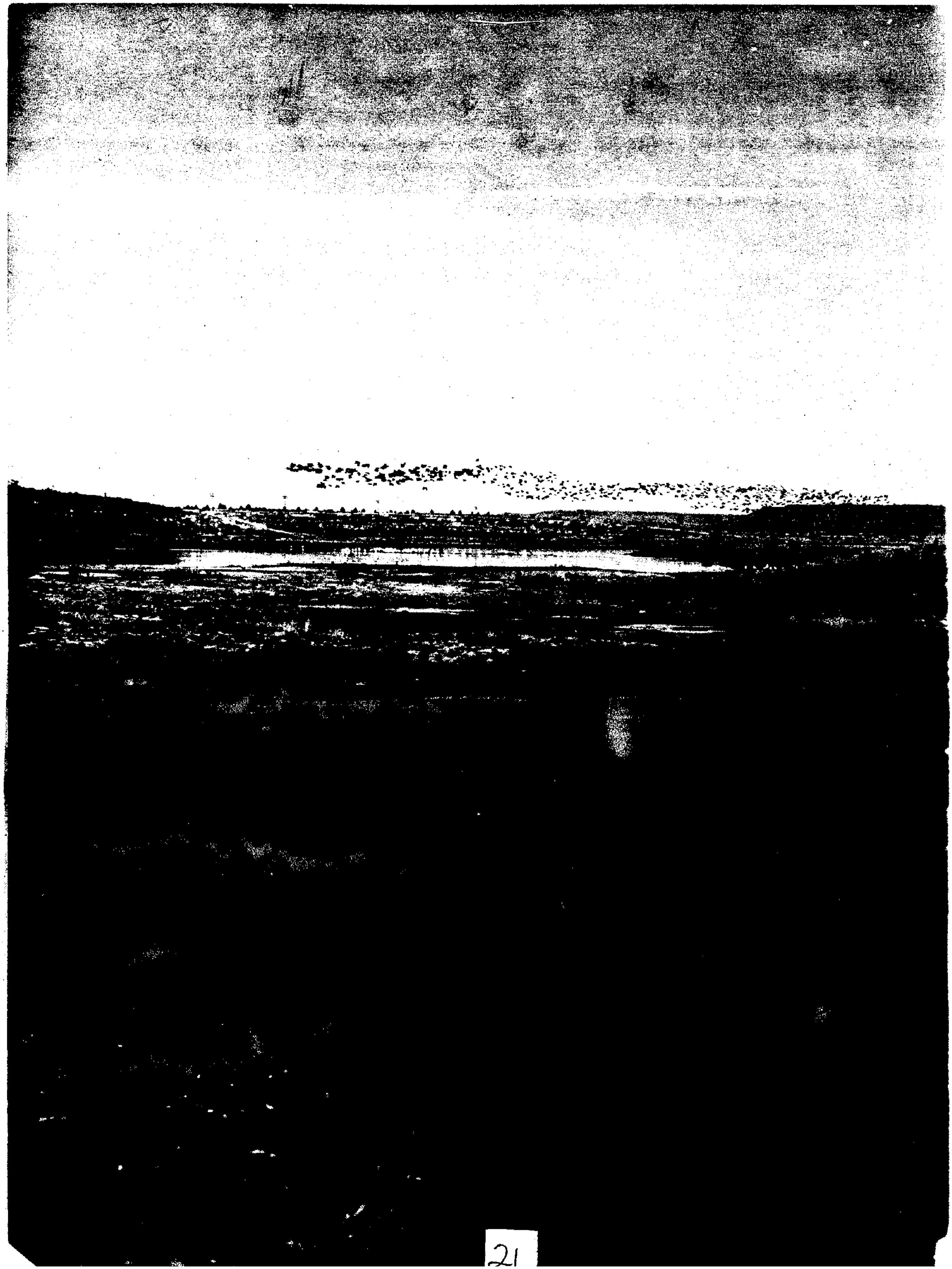
Low elevation wetlands that have a maximum interaction with water have more wetland functions and values than do high elevation wetlands which only occasionally interact with water. If there is potential for wetland diversification, the greatest enhancement in wetland functions and values will be realized by converting existing wetlands to lower elevation ones that are connected to open water. This will introduce improved water and material exchange (export-import) throughout the contiguous unconverted wetlands. It will provide increased edge and an improved habitat for fish and wildfowl. It will offer an improved potential for water quality control. Additionally, the lower wetland will have a greater longevity than the higher one.

2.3.5 **Other Measures.** Depending upon pre-construction site conditions, other possibilities for enhancement may exist. There may be opportunities to increase scenic, recreational, and educational uses of the area. Sedimentation of the wetland from upland sources may be reduced by constructing sediment traps at point sources such as storm drains. There may be opportunities for storm water management. Mosquito control measures might be considered. Such measures could be part of a wetland diversification design. Meanderizing (making nonlinear) linear dredged channels, constructing bird platforms, or altering existing stream beds (e.g., emplacement of bolders and stone) for improved fish habitat are additional possibilities to consider.



Diversification of existing monotypic wetlands to provide improved wetland functions may be an acceptable enhancement proposal.

This wetland, created in conjunction with the construction of Route 395 in Modoc County, California, provides an interspersion of open water and earth knolls as nesting areas of geese.



3. Procedures for Wetland Establishment

Whether wetlands are to be restored or replaced, the procedures for establishing wetlands are the same. These procedures are typical of standard landscaping ones, except that the final grade is much more critical for wetland establishment.

3.1 Site Selection

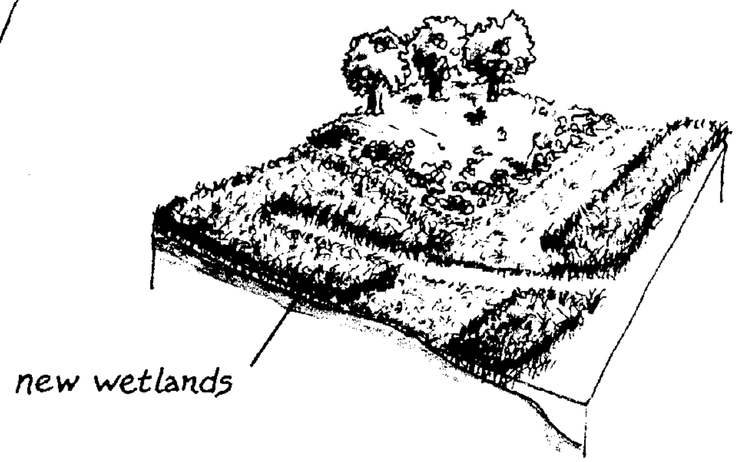
Considerations and criteria for selecting an appropriate site have been previously discussed in Section 2.1.2. No site needs to be selected when only wetland restoration is necessary. But when a wetland replacement site is required, the appropriate regulatory and consulting resource agencies should be invited to participate in its selection. Site selection should be conducted early in the highway planning process.

3.2 Landscape Architecture and Engineering Designs

The single most important factor in wetland establishment is creating the proper elevation. The mean tidal or water elevations during the growing season are determined following selection of the site and finalization of a compensation plan. A topographic and/or bathymetric (water bottom) survey of the site and of any wetlands associated with the site is made and correlated with the tide or water level datum previously determined. The vegetative composition of nearby wetlands is correlated with their topography. Water salinities, if applicable, are determined. This information will be useful in designing final grades and associated vegetative zones. Accurate topographic and water level data are critical for successful wetland establishment.

Any necessary soil borings are taken and analyzed, and required hydrological and engineering studies are conducted. These latter studies normally would be necessary only for complex projects requiring structures and water management. A conceptual landscape and engineering design is developed and included in the mitigation section of the environmental document. This design should reflect all of the compensation and enhancement measures that are proposed for mitigation.

After agency review, the final design and specifications are



The most important factor in successful wetland establishment is elevation. After the selection of a wetland replacement location, a thorough topographic survey of the site and of contiguous or nearby wetlands is made. Existing wetlands that utilize the same water source as the proposed new wetland are useful bench marks for developing the landscape design and grading plan.

developed. An essential element of the final design is a detailed site grading plan. The plan may require 6-inch elevation contours throughout the areas to be vegetated, depending upon (1) the plant species designated for establishment and their respective sensitivities to water depths and (2) the tidal or water level range for the new wetland (the lower this range, the more critical the final grade). All channelization requirements for water circulation and for the import and export of nutrients and particulate matter are included in this plan as are any storm water management and sedimentation control requirements. Detailed plans are developed for any containment, breakwater, erosion control, and water level control structures that may be required.

Then specifications are developed for plant species, plant materials, plant species distribution (vegetative zonation), planting (including time limitations), fertilization, water level control, and site maintenance.

The landscape architecture and engineering design requirements for wetland restoration are less complex than for wetland replacement. The site grading plan should conform to the pre-existing topography of the site. The vegetation to be established should be the same as the pre-existing vegetation. Water level data is not required, and normally there are no structures to design. When some enhancement measure, alone or included with restoration, requires elevations that differ from the pre-existing ones, more detailed landscape architecture and engineering designs will be required.

3.2.1 **Outside Consultation Requirements.** The need to retain outside consultation for assistance with site selection and with landscape architecture design will depend upon the complexity of the wetland establishment project and the existing in-house expertise. One purpose of this manual is to reduce such need and to provide some in-house capability to move ahead, at least at the conceptual level.

3.2.2 **Contract Considerations.** When feasible, it is most desirable to issue a separate contract for the performance of the compensation and/or enhancement work—at least for the fine grading and vegetative work. This will reduce the number of change orders and/or litigations associated with the highway project. It will also provide the best insurance for success.

Most general construction and landscape contractors that bid on highway projects are not knowledgeable about wetland construction techniques and methods nor are they sensitized to the factors that limit success. If a separate contract is issued for the compensation-enhancement work, and if the contract specifications are detailed, most of the contractors unfamiliar with compensation work will bid high or not bid because of inexperience. Those contractors that have had some experience with wetlands will bid competitively and will probably do a better job.

3.3 Site Preparation

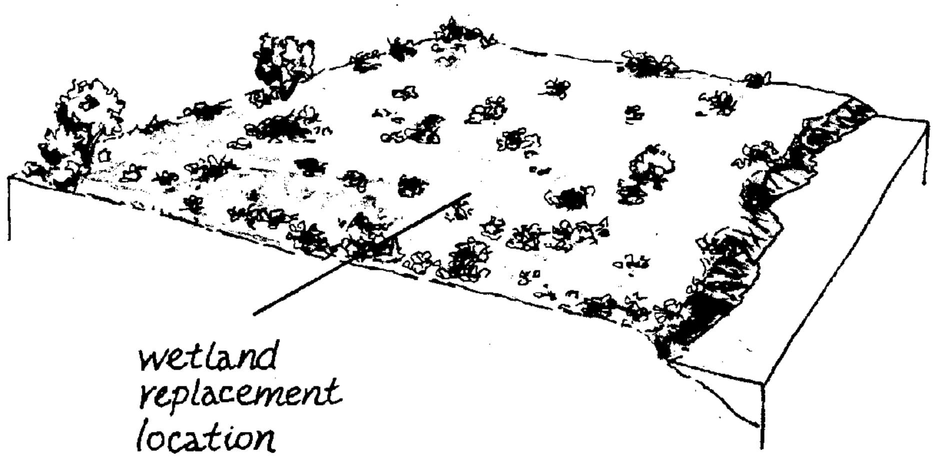
More often than not, the preparation of the site will involve excavation rather than filling operations. In either case, however, the object of the required work is to bring the site to the final grade within the specified tolerances. The methods for doing the work normally are not specified, but left up to the contractor.

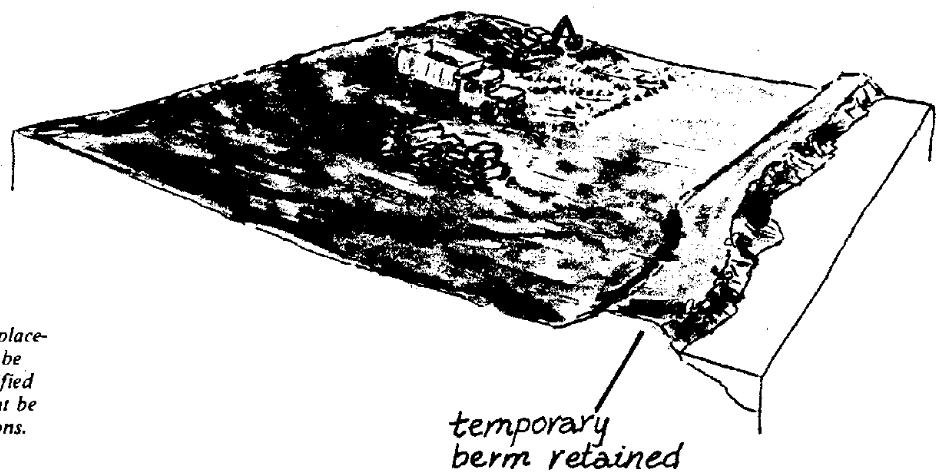
No matter what the grading method, fine grading under water probably will not lead to the desired grade within the specified tolerances. Excluding water from the site during excavating, grading, channelizing, and maybe planting are major considerations. Certain specifications pertaining to the exclusion of water might be made part of the contract.

Specifications might require retention of a portion of land as a dike to exclude water. Constructing a temporary dike might also be necessary. In tidal areas the earthen dikes could be temporarily opened at low tide to release accumulated ground and rain water. In non-tidal areas, water may have to be continually or periodically pumped out of temporary collection basins.

It may not be practicable or even feasible to exlude water from a site that involves filling—particularly in open water areas or if the fill material is hydraulically pumped. In such instances, precision grading of the site may not be possible, particularly if the fill materials are muds. The site grading plan should reflect this potential difficulty and specify the scattered mounding of fill materials in order to diversify the wetland habitat.

Topsoiling (loaming) the graded area normally will not be required. Substrate properties and characteristics do not limit the successful establishment of a wetland. There are preferred substrate types for various plant species; however, most clean (uncontaminated) substrates are acceptable. Consequently, what results after excavation or filling generally will be acceptable. However, excavations into bedrock would be unacceptable as would be filling with rock and stone. Further discussion regarding substrate specifications is provided in a following section.





Excluding water from the wetland replacement site during its preparation may be essential in order to achieve the specified grades. Techniques for so doing might be made part of the contract specifications.

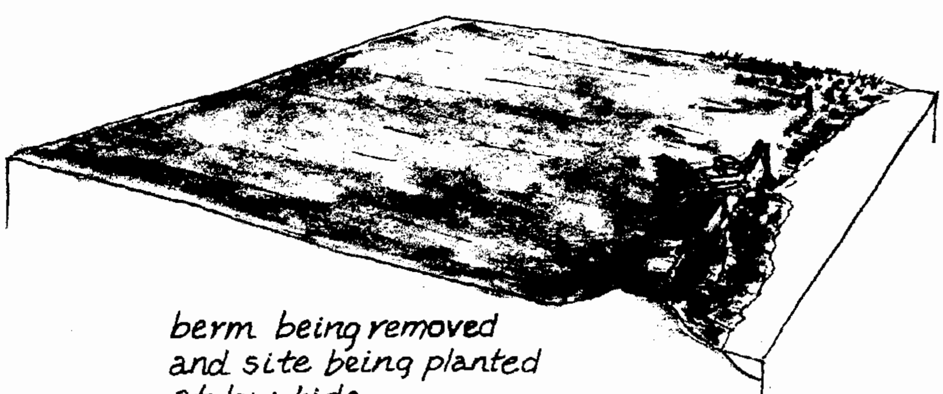
3.4 Vegetative Establishment

In the replacement and restoration of wetlands and in measures for enhancement that involve revegetation, it is important to get the designated plants growing and exhibiting maximum ground coverage and productivity as quickly as possible. This improves the mitigation, because the lost wetland has been compensated for expeditiously. Additionally, leaving a graded site unvegetated will promote its instability, and grades altered by erosion may not support the designated plants.

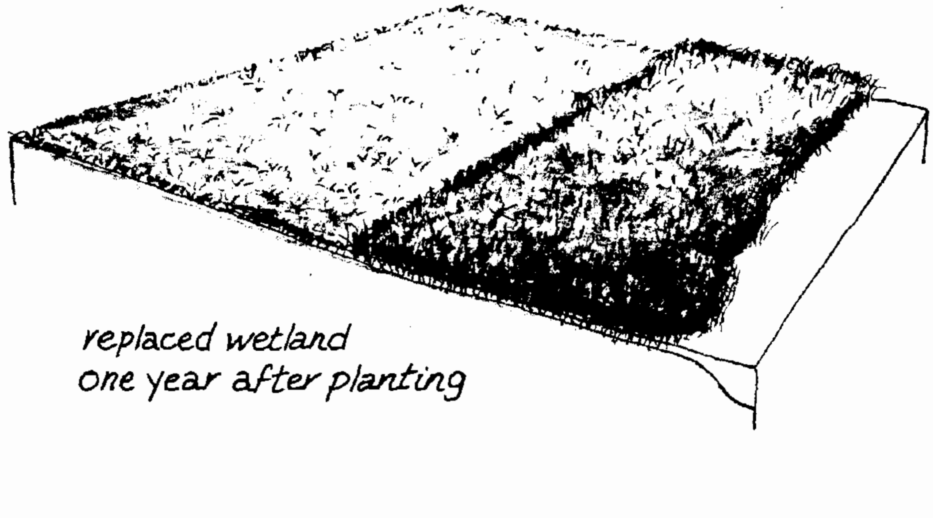
In time, unvegetated sites that retain proper elevations may become naturally vegetated by wetland plants. This is least likely to occur rapidly in saltwater areas and is most likely to occur in freshwater areas. However, there is little control over what plant species will enter such unvegetated sites. Those that do may not be most effective in achieving the desired compensation. Consequently, a mitigation plan should specify intentional establishment of vegetation throughout a prepared site.

3.4.1 **Obtaining and Handling Plant Materials.** Some wetland species have known distinct varieties which develop abnormally outside their geographic range. Unless contrary information is available, only indigenous plant materials should be used for a wetland establishment project, and these materials should be collected within a 100-mile radius of the project site.

The necessary plant materials may be available from a wetland plant nursery (see Section 4 and Appendix A). They may have to be collected from the wild. Any requisite permits for such collections must be obtained from the state and federal wetland regulatory agencies.



berm being removed
and site being planted
at low tide



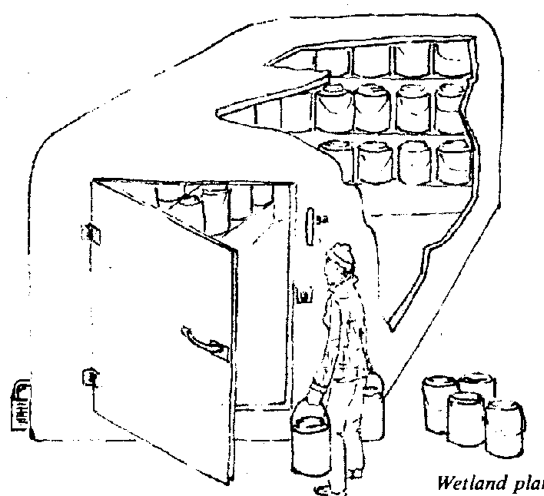
replaced wetland
one year after planting

Wetland plant seeds normally are harvested in the wild. Conditions preclude the use of conventional equipment and limit techniques to time consuming hand ones. Harvesting must be accomplished within a period of about one month during the year.

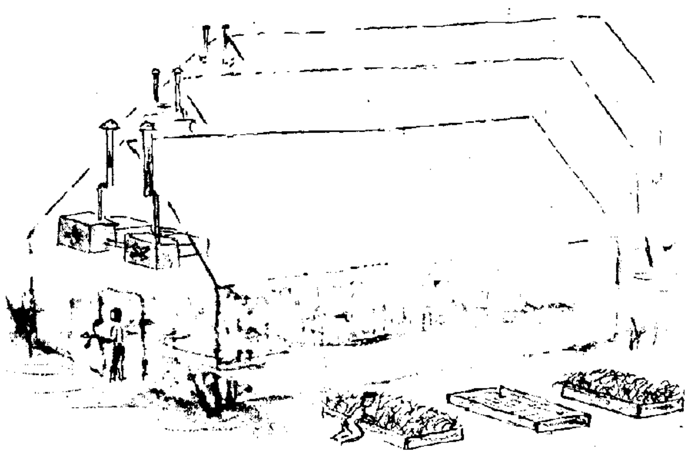
Some wetland plant seeds can be threshed and cleaned using standard equipment. Others have to be processed by hand.

Seed harvest is restricted to a period of three to four weeks during or toward the end of the growing season. If this narrow harvest period is past when the landscape contract is awarded, the project may be delayed for up to one year. In order to avoid this occurrence, highway department biologists might harvest, process, and store the necessary seeds (or contract separately to have others do this) and then provide the landscape contractor with the seeds at an appropriate time.

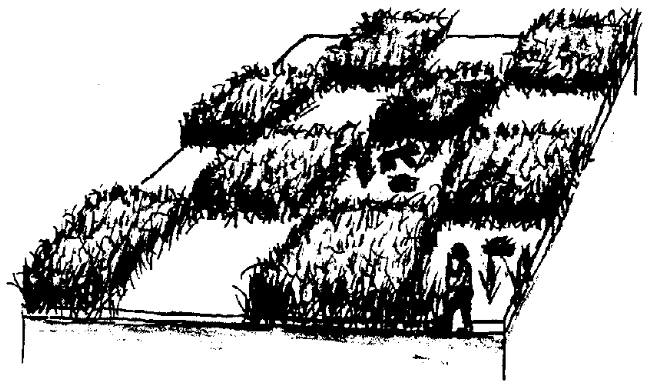
After harvest, the seeds are threashed, cleaned, and stored. Seeds often are stored wet and generally under refrigeration. Following afterripening (a period of storage, generally cold, that may be required before seed germination is possible), the seeds can be used to propagate the required nursery stock for the project or used directly for seeding the site.



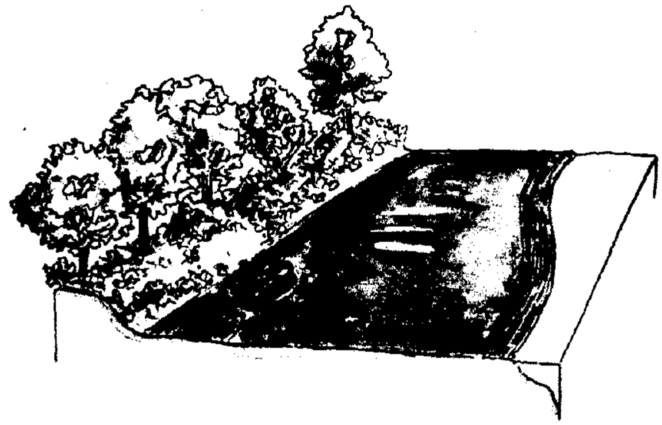
Wetland plant seeds often must be stored wet and under refrigeration.



Wetland plant seeds are used to produce nursery plant stock or to seed the site directly.



When digging transplant materials from natural wetlands, it is recommended to use a checkerboard technique to avoid the disruption of single large areas of wetlands.



Seeds must be cultivated to subsurface depths of generally no greater than one inch. Seeds that are surface sown, with or without mulch, will wash away during times of high water.

If plant materials other than seeds are specified, they may not be available from a nursery and the landscape contractor may have to collect them from the wild. Such materials may be bare root plants (sprigs—dormant or growing plants, usually grasses and sedges, with substrate removed from the roots), below-ground perennial plant parts (tubers, bulbs, rhizomes), and excavated clumps of plants and associated substrate (plugs). These materials are dug from existing wetlands. Digging should be by hand and be in checkerboard fashion to avoid mutilation of large areas of wetlands. Plugs may be difficult to obtain under water, but the other materials are best so obtained to facilitate washing away the substrate. The excavated plant materials normally are transported directly and transplanted to the site. During the interim, these materials must be kept moist.

It should be mentioned that digging up natural wetlands for the purpose of establishing new wetlands is contrary to the mandates for wetlands preservation and to the concept of mitigation. A better method of obtaining materials is through the establishment of qualified nurseries to propagate and supply required wetland plant materials.

3.4.2 **Seeding.** Wetland establishment by seeding is the most economical approach, but its success is least predictable. Seed germination and seedling development in shallow water or throughout the low half of the vegetation zone in tidal areas depend upon uncontrollable parameters such as the temperature and the turbidity of the water. Soil and water salinities may limit seeding success. Frequent siltation of the foliage leads to reduced productivity or mortality of the seedlings. Poorly developed seedlings may not overwinter in some regions of the country and they are most vulnerable to animal depredation.

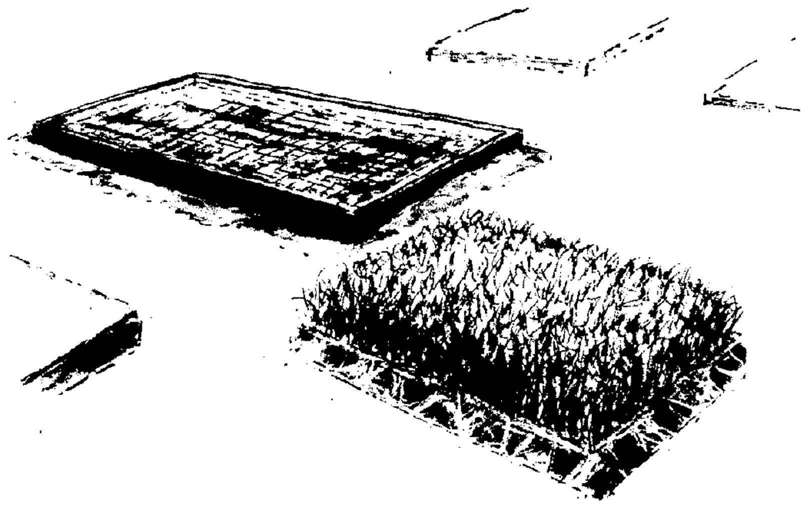
In order to capitalize on the full growing season, seeding generally must be completed in early spring. Seeding is best accomplished using standard cultivation equipment and with the site drained. Hydroseeding techniques generally are not applicable. Seeding in shallow water may be feasible for seeds having a greater density than that of the water; seeding underwater is difficult to control and once the seeds have germinated, the seedlings may float to the surface.

At least one fertilization normally will be required. This is best accomplished after the seeds have germinated and the seedlings are about one month old. If fertilization is conducted as described in Section 5, loss of nutrients to the interacting surface water will be minimized.

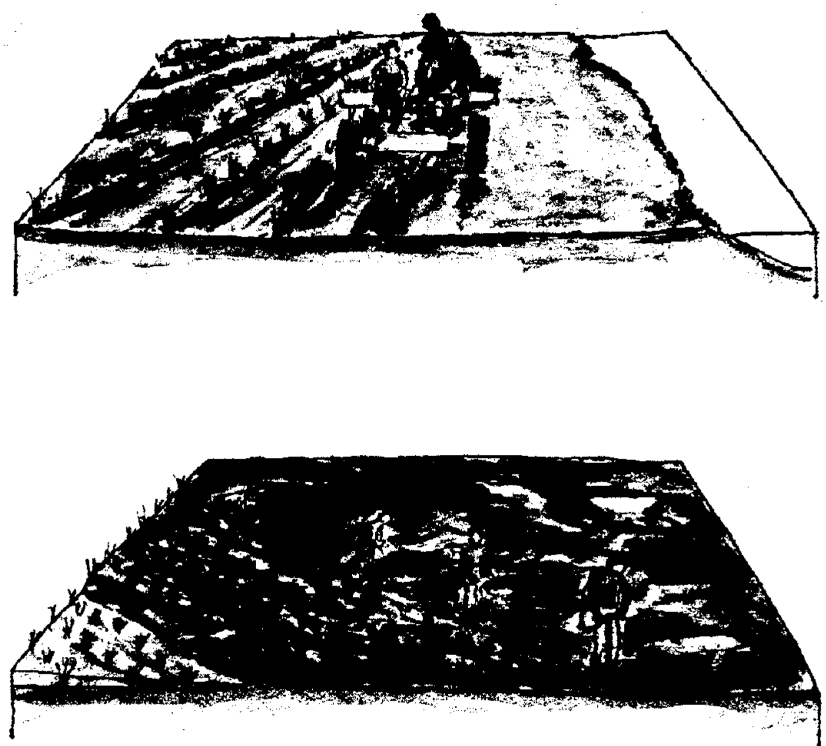
3.4.3 **Transplanting.** The most successful as well as the most expensive method of wetland establishment is transplanting peat-potted plants, plugs, sprigs, and dormant underground plant parts (tubers, bulbs, rhizomes). These plant materials have either the top growth or the stored energy to emerge from the water level and sustain maximum productivity after planting.

If available and if production is possible, peat-potted nursery stock developed from seed or sprigs is the preferred plant material. This plant stock may be transplanted at any time of the year—in a growing condition or in a dormant one. Time delays in preparing the site will not affect the success of wetland establishment. Appropriately sized plugs from natural wetlands may be planted successfully any time. Normally, sprigs, tubers, bulbs, and rhizomes must be transplanted before new growth commences. This limits the optimal planting times to winter and spring months.

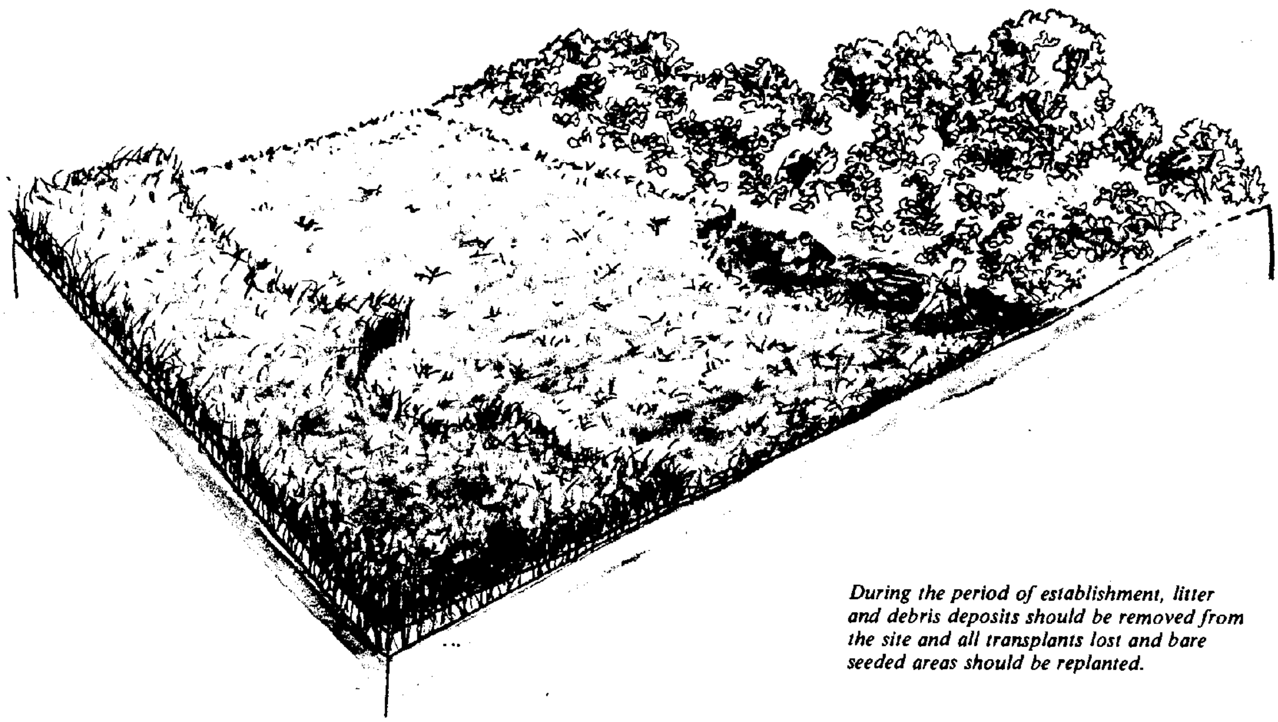
Depending upon the area and the capacity of the site to support conventional equipment, plant stock may be transplanted to drained areas mechanically or by hand. Planting underwater or planting dormant underground plant propagules must be done manually. Controlled release fertilizer normally is applied at the time of planting and again only as plant conditions warrant.



Peat-potted nursery stock of aquatic plants can be produced economically outside or in a greenhouse in water-filled compartments.



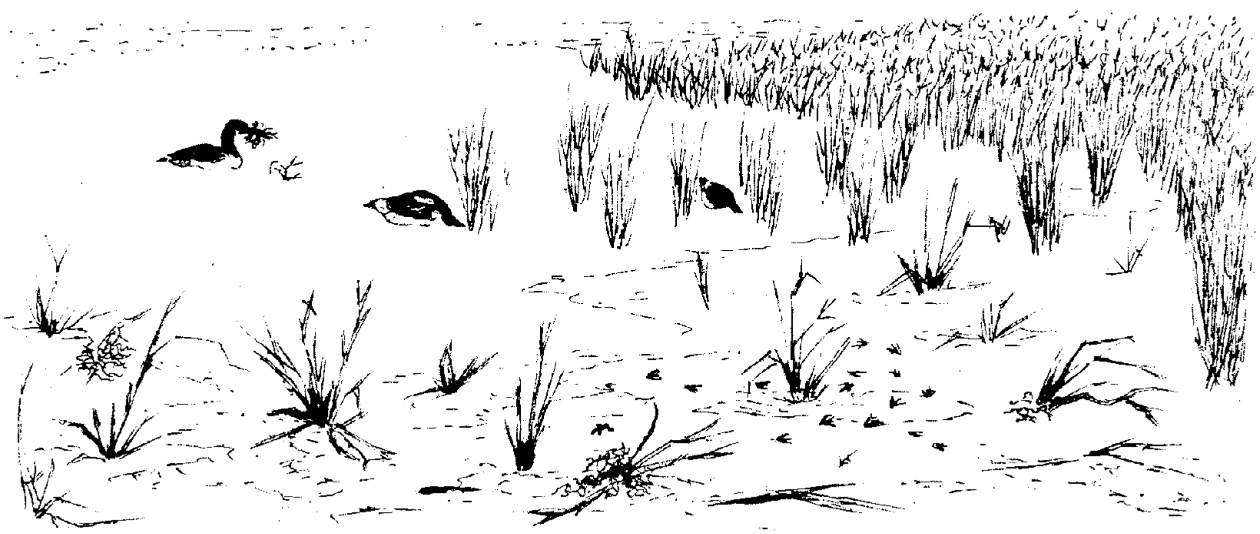
If the physical conditions of a site permit, plants can be transplanted mechanically. Otherwise, transplanting must be done by hand.



During the period of establishment, litter and debris deposits should be removed from the site and all transplants lost and bare seeded areas should be replanted.

3.5 Period of Establishment

Maintenance of the site after planting and through at least one full growing season should be part of the general contract or the landscape contract. Litter and debris deposits which adversely impact mature wetlands might demolish transplants or seedlings unless removed expeditiously. Wildlife tend to concentrate on isolated plants. Seedlings and transplants are most vulnerable until ground cover is maximized. Exclosures to prevent wildlife intrusion may be needed for some sites. Plants lost from wildlife feeding, debris deposits, erosion, vandalism, washing out, or other causes should be replaced during the period of establishment.



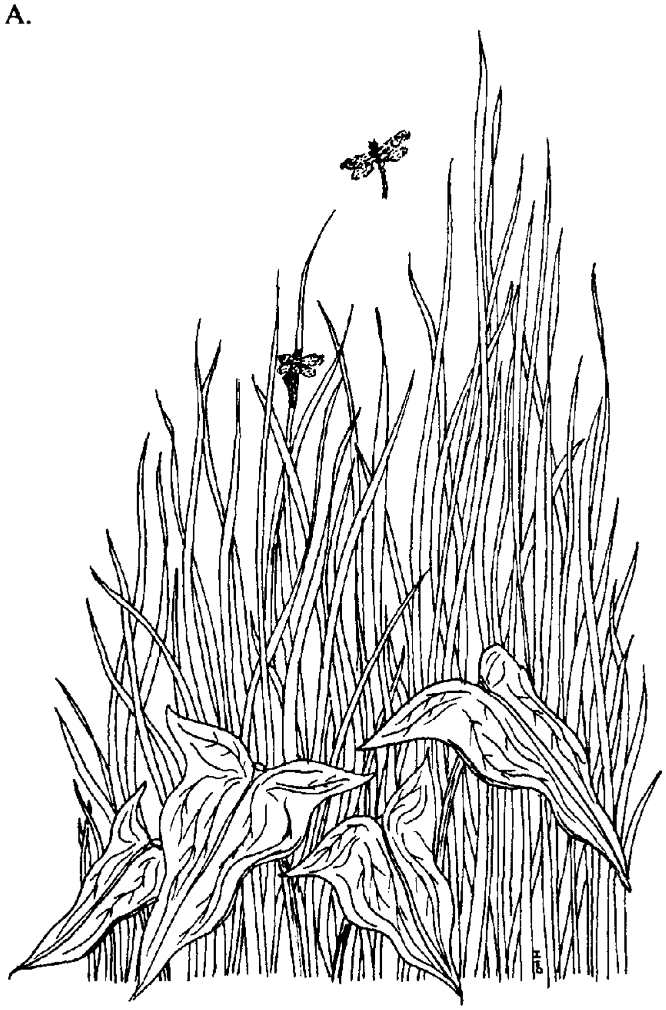
If wildlife or livestock populations near a new wetland site are known to be large, the site may have to be protected during the period of establishment by using exclosures.

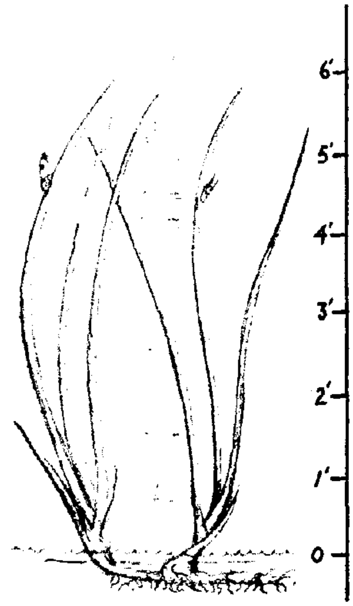
4. Target Perennial Wetland Plants

Selected perennial wetland plants that are commonly encountered throughout the United States are provided next. The plants selected are those which (1) have been successfully utilized in wetland establishment projects, (2) have been successfully developed and propagated in nurseries, or (3) have potential for (1) and (2). These plants are valuable as substrate stabilizers, water purifiers, and food and cover for fish and wildlife. The following abbreviations are used: MLW = mean low water, MT = mean tide, MHW = mean high water, MHHW = mean higher high water, ST = spring tide. The numbers listed after "commercial sources" refer to nurseries listed in Appendix A.

List of Species in the Order Presented

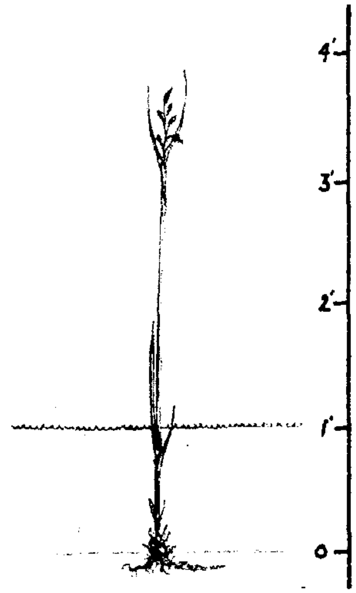
Acorus calamus (sweetflag)
Carex lyngbyei (Lyngbye's sedge)
Carex obnupta (slough sedge)
Cephalanthus occidentalis (buttonbush)
Deschampsia caespitosa (tufted hairgrass)
Distichlis spicata (salt grass)
Festuca arundinacea (Ky-31 tall fescue)
Leersia oryzoides (rice cutgrass)
Mangroves
Panicum virgatum (switchgrass)
Peltandra virginica (arrow arum)
Polygonum spp. (smartweeds)
Pontederia cordata (pickerelweed)
Sagittaria spp. (arrowhead)
Saururus cernuus (lizardtail)
Scirpus americanus (common three-square)
Scirpus robustus (saltmarsh bulrush)
Spartina alterniflora (smooth cordgrass)
Spartina cynosuroides (big cordgrass)
Spartina patens (saltmeadow cordgrass)
Typha spp. (cattail)
Submerged aquatic plants





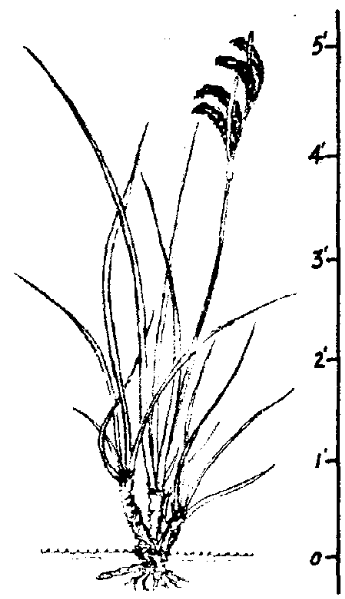
Acorus calamus (sweetflag)

Geographic range:	Northeastern U.S., central plains, scattered northwest
Habitats:	Fresh marshes and wet places, standing water 0-1 ft, MHW and above, tolerates some shade, drought
Commercial sources:	2,5,6,11,15,16
Recommended propagules:	Rhizome
Site seeding potential:	Low



Carex Lynbyei (Lynbye's sedge)

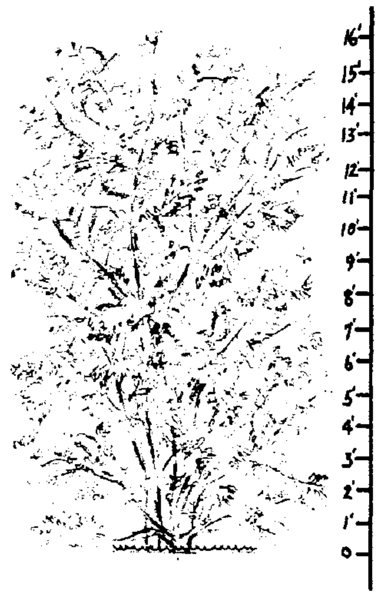
Geographic range:	West Coast
Habitats:	Fresh marsh and salt marsh, MT to MHHW
Seed harvest & storage:	July-Sept, dry at room temperature
Recommended propagules:	Peat pots, sprigs
Site seeding potential:	Low



Carex obnupta (slough sedge, Pacific sedge)

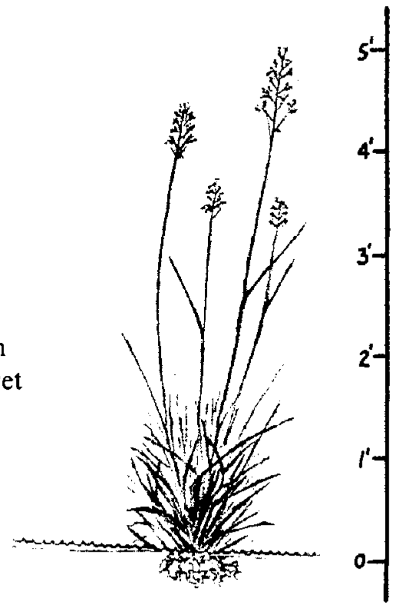
Geographic range:	West Coast
Habitats:	Freshwater to brackish water, MHW and above
Seed harvest & storage:	July-Oct, wet, no afterripening
Recommended propagules:	Peat pots, sprigs
Site seeding potential:	Low

Cephalanthus occidentalis (buttonbush)



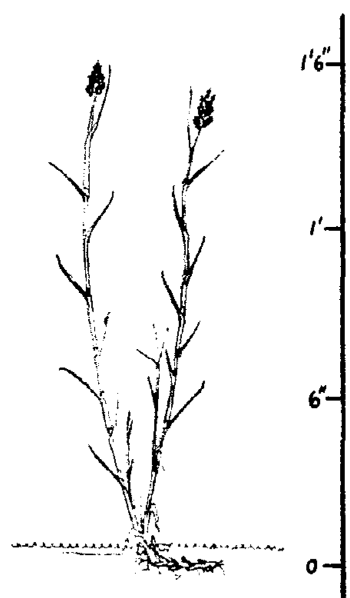
Geographic range:	Maine to Texas, occasionally inland, California
Habitats:	Fresh swamps, standing water 0-3 ft, MHW and above, tolerates shade, fluctuating water levels
Commercial sources:	1
Seed harvest & storage:	Sept-Nov, 4°C in tapwater or dry in closed containers, no afterripening
Recommended propagules:	Seeds, peat pots
Site seeding potential:	Low

Deschampsia caespitosa (tufted hairgrass)



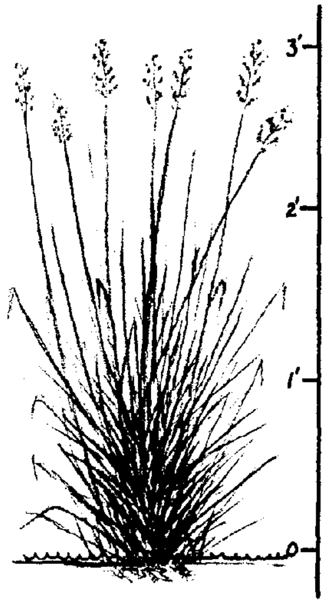
Geographic range:	Northern half of U.S.
Habitats:	Coastal fresh marsh and brackish marsh, MHW to ST, inland in wet meadows, not in standing water
Seed harvest & storage:	July-Sept, wet or dry, after-ripening required
Recommended propagules:	Seeds, peat pots, sprigs
Site seeding potential:	High

Distichlis spicata (salt grass, spike grass, alkali grass)



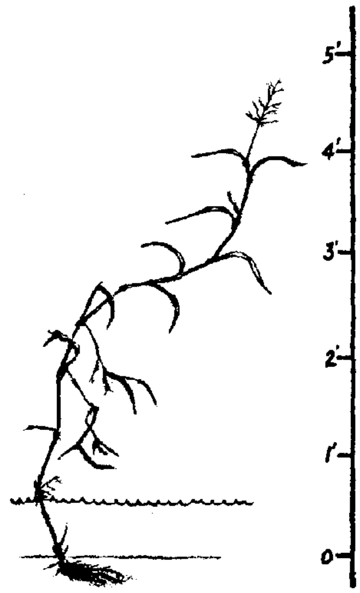
Geographic range:	Maine to Texas, locally inland to Missouri, Pacific coast
Habitats:	Salt marsh, moist saline soils, alkaline soils, sand dunes, MHW and above
Commercial sources:	1,9
Seed harvest & storage:	Aug-Oct, 4°C dry in closed containers
Recommended propagules:	Seeds, sprigs; peat pots
Site seeding potential:	High

Festuca arundinacea (Ky-31 tall fescue)

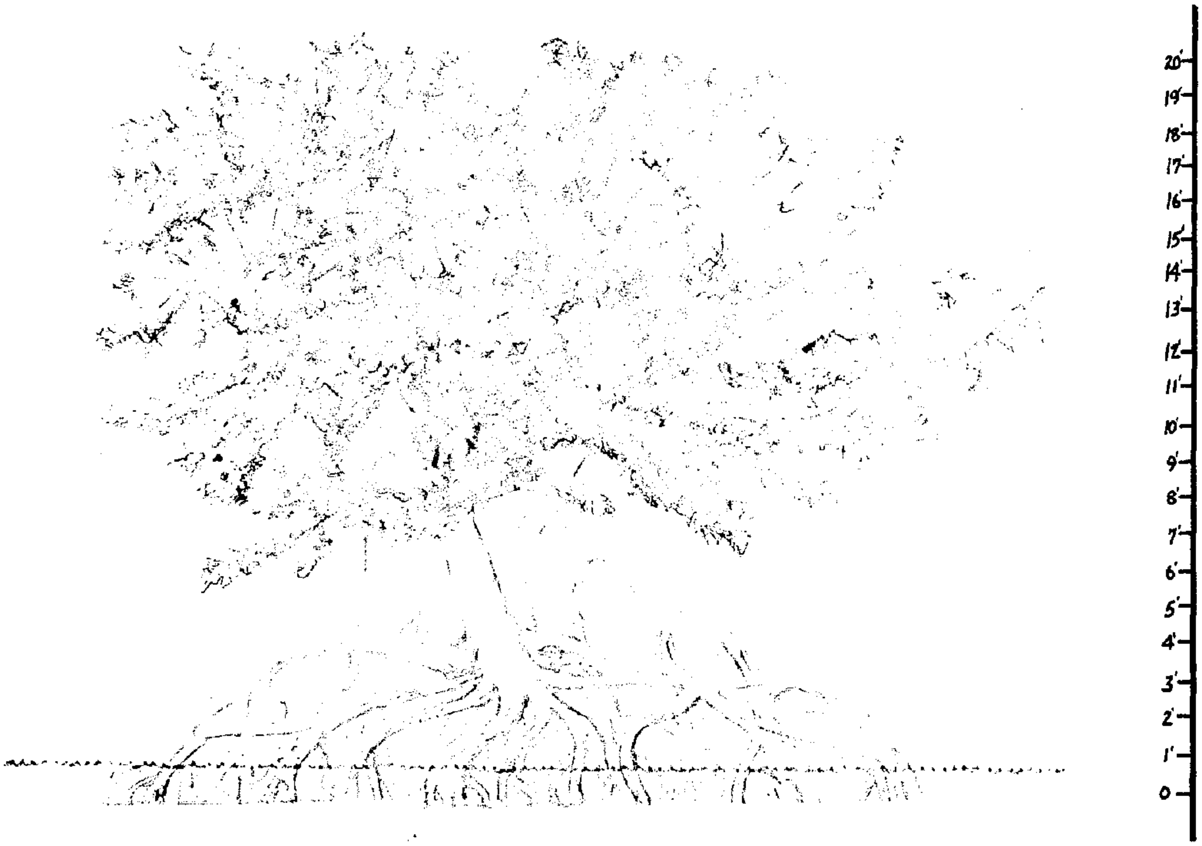


Geographic range:	Throughout U.S.
Habitats:	Upland, dry to wet soils, MHW and above in tidal brackish water areas, mature plants tolerate water salinities up to 10 ppt after established, seed will germinate in water salinities up to 2 ppt
Commercial sources:	At most outlets for field crops
Seed harvest & storage:	Apr-June in south, May-Aug in north, dry, cool
Recommended propagules:	Seeds
Site seeding potential:	High

Leersia oryzoides (rice cutgrass)



Geographic range:	Throughout U.S. except Nevada, Montana, Wyoming
Habitats:	Fresh marsh, standing water 0-1 ft, tolerates shade, drought, flooding
Commercial sources:	1
Seed harvest & storage:	Aug-Oct, 4°C in tapwater or dry in closed container
Recommended propagules:	Seeds, peat pots, sprigs
Site seeding potential:	High



MANGROVES

Avicennia germinans (black mangrove)
Rhizophora mangle (red mangrove)
Laguncularia racemosa (white mangrove)

Geographic range:	Florida, *A. germinans*—Florida to Texas
Habitats:	Salt marshes, about MT to above MHW. *R. mangle* tolerates standing water up to 1 ft. *A. germinans* tolerates standing water to several inches, highest salinities, coldest temperatures, adverse conditions. *L. racemosa* tolerates driest soil
Commercial sources:	4,8
Seed harvest & storage:	*R. mangle*—July to Oct plant immediately
Recommended propagules:	Saplings (2-3 year), seeds
Site seeding potential:	High in protected areas only
Comments:	Initial stabilization of substrate by *Spartina alterniflora* results in greater success in establishing mangroves. The mangroves will shade out *S. alterniflora* gradually.

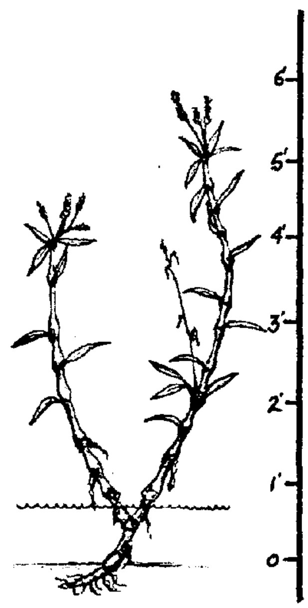
Panicum virgatum (switchgrass)

Geographic range:	Throughout U.S. except Pacific coast
Habitats:	Fresh marsh and salt marsh above MHW, inland moist and dry soils
Commercial sources:	3,5,7,10,12,13
Seed harvest & storage:	Aug-Oct, 4°C dry in closed containers, cool area, some evidence for afterripening
Recommended propagules:	Seed, peat pots
Site seeding potential:	High

Peltandra virginica (arrow arum, tuckahoe, wampee, duck corn)

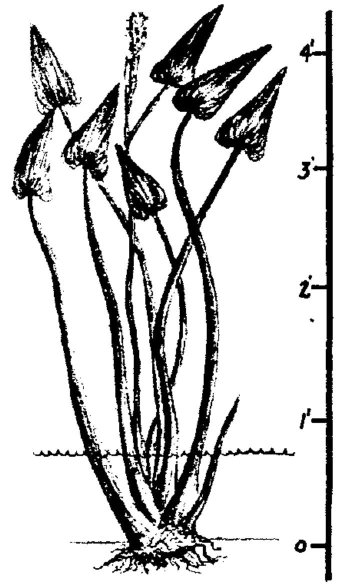
Geographic range:	Eastern U.S.
Habitats:	Fresh marshes, standing water 0-1 ft, MT to MHW, tolerates shade
Commercial sources:	1,5,15
Seed harvest & storage:	Oct (MD), 4°C wet
Recommended propagules:	Seeds
Site seeding potential:	High

Polygonum spp. (smartweeds)



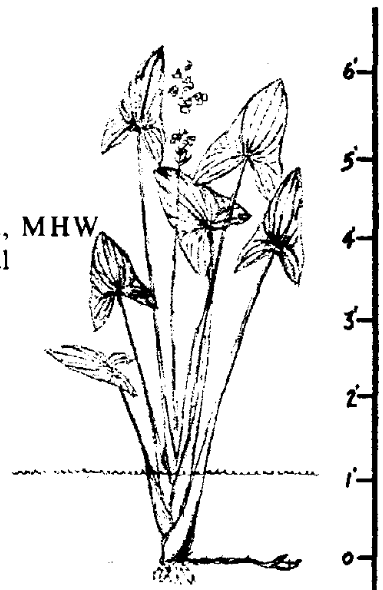
Geographic range:	Throughout U.S.
Habitats:	Fresh marshes, standing water 0-2 ft, some species tolerate (1) brackish (*P. densiflorum, P. punctatum*), (2) alkaline, (3) dry, or (4) turbid conditions (*P. amphimium, P. muhlenbergii*)
Commercial sources:	5,7,9,15
Seed harvest & storage:	Oct-Nov (MD), 4°C in tapwater or dry in closed containers
Recommended propagules:	Seeds, peat pots
Site seeding potential:	High
Comments:	Annual species (e.g., *P. lapathifolium, P. pensylvanicum, P. persicaria*) have high potential for use

Pontederia cordata (pickerelweed) *Pontederia lanceolata* (possibly a separate species)



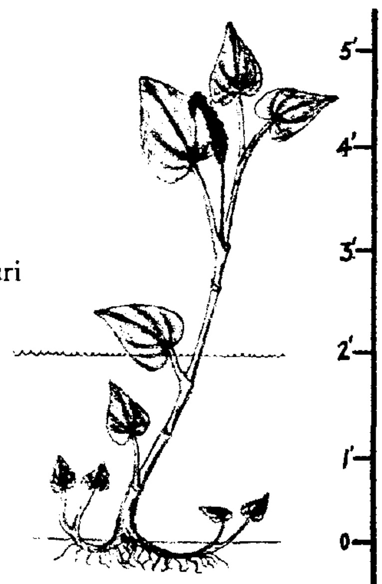
Geographic range:	Eastern U.S., *P. lanceolata* Virginia to Texas
Habitats:	Fresh marsh and brackish (up to 1 ppt salt) marsh, standing water 0-1 ft, MT to MHW
Commercial sources:	1,5,6,11,15,16
Seed harvest & storage:	Sept-Oct, 4°C in tapwater, afterripening likely
Recommended propagules:	Tubers, peat pots
Site seeding potential:	Low

Sagittaria spp. (arrowhead, duck potato, wapato)



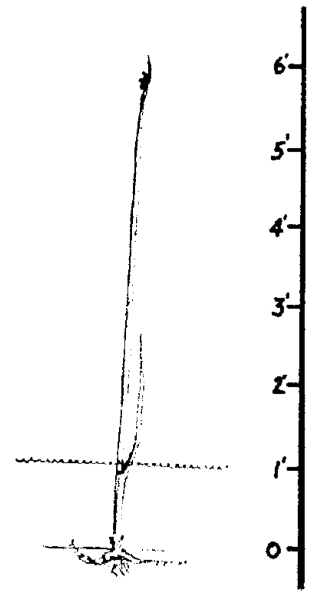
Geographic range:	Throughout U.S.
Habitats:	Fresh marsh, standing water 0-2 ft, MHW and above, some spp. tolerate total submergence, some tolerate shade, some tolerate up to 1 ppt salt
Commercial sources:	1,5,6,7,11,14,15,16
Seed harvest & storage:	Oct (MD), 4°C wet
Recommended propagules:	Tubers, peat pots
Site seeding potential:	Low
Comments:	*S. cuneata* and *S. latifolia* are most valuable to wildlife

Saururus cernuus (lizardtail, water dragon, swamplily)



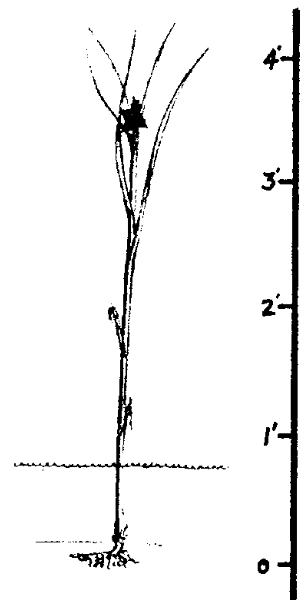
Geographic range:	Maine to Texas, New York, Illinois, Michigan, Kansas, Missouri
Habitats:	Fresh swamps, standing water 0-3 ft, tolerates shade
Commercial sources:	1,16
Seed harvest & storage:	Aug-Oct, 4°C in tapwater or dry in closed container, no after-ripening
Recommended propagules:	Seeds, peat pots, rhizomes
Site seeding potential:	High

Scirpus americanus (common three-square, American three-square, three-square rush, swordgrass)



Geographic range:	Throughout U.S.
Habitats:	Inland fresh marsh and alkali marsh, standing water 0-1 ft, coastal fresh marsh and brackish (<10 ppt salt) marsh, MT to above MHW
Commercial sources:	1,5,9
Seed harvest & storage:	July-Oct, 4°C in tapwater, afterripening likely
Recommended propagules:	Peat pots, sprigs, seeds
Site seeding potential:	High

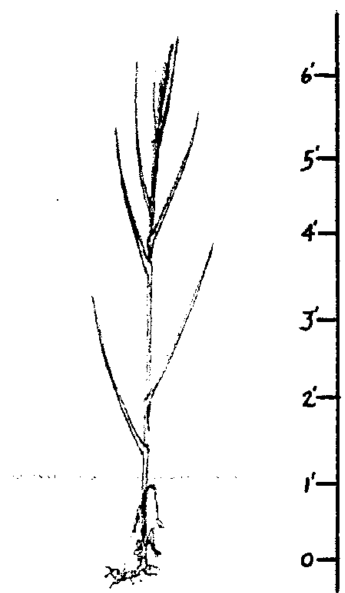
Scirpus robustus (saltmeadow bulrush)



Geographic range:	Maine to Texas, California, Washington
Habitats:	Brackish marsh and salt marsh, about MHW and above
Commercial sources:	1,9
Seed harvest & storage:	Aug-Oct, 4°C in tapwater or dry in closed containers
Recommended propagules:	Peat pots, sprigs, seeds
Site seeding potential:	High

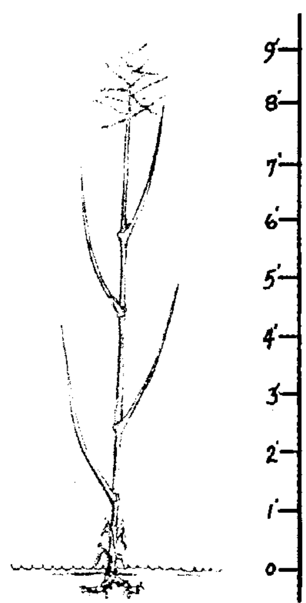
Spartina alterniflora
(smooth cordgrass, salt marsh cordgrass)

Geographic range:	Maine to Texas (Washington and California introduced)
Habitats:	Coastal salt marsh, MLW to MHW for tidal range below 2 ft; MT to MHW for tidal range above 3 ft
Commercial sources:	1,4,8,9
Seed harvest & storage:	N. Atlantic in Sept, mid-Atlantic in Oct, S. Atlantic and Gulf—difficult due to extended flowering periods, store 4°C in 10-40 ppt saltwater, several months afterripening required for mid-Atlantic and northern populations
Recommended propagules:	Seeds, peat pots, sprigs
Site seeding potential:	High in protected areas and at upper elevation limit
Comments:	Distinct varieties exist in the N. Atlantic, mid-Atlantic, and Gulf regions. *Spartina foliosa* (Pacific cordgrass) is found in California. It occupies the same habitat as *S. alterniflora* and is similar in appearance.

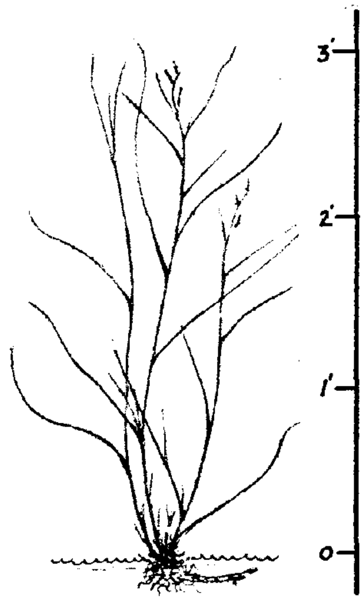


Spartina cynosuroides
(big cordgrass, salt reed grass)

Geographic range:	Massachusetts to Texas
Habitats:	Fresh marsh to brackish (< 10 ppt salt) marsh, MHW and above
Commercial sources:	1
Seed harvest & storage:	Oct, 4°C in tapwater or dry in closed containers, afterripening required
Recommended propagules:	Seeds, peat pots, sprigs
Site seeding potential:	High in protected areas and above MHW

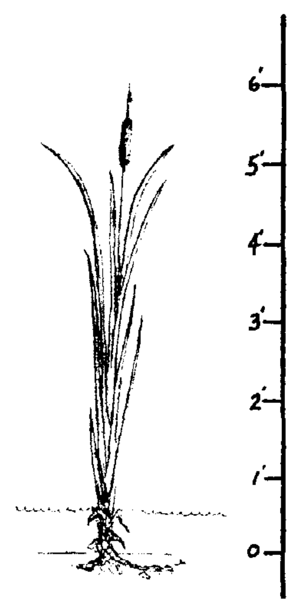


Spartina patens
(saltmeadow cordgrass, salt marsh hay, highwater grass)



Geographic range:	Maine to Texas, inland New York, Michigan
Habitats:	Salt marsh above MHW to sand dunes, rare inland
Commercial sources:	1,4,8
Seed harvest & storage:	N. Atlantic in Sept, mid-Atlantic in Oct, 4°C dry in closed container, afterripening takes several months for N. Atlantic and mid-Atlantic varieties
Recommended propagules:	Peat pots, sprigs
Site seeding potential:	Low

Typha spp. (cattail)



Geographic range:	*T. latifolia*—throughout U.S. *T. augustifolia*—Maine to South Carolina California, West Virginia, Kentucky, Missouri, Nebraska
Habitats:	*T. angustifolia*—brackish (< 10 ppt salt) marsh, both—fresh marshes, standing water 0-0.5 ft, MHW and above
Commercial sources:	1,2,5,6,9,11,14,15
Seed harvest & storage:	Sept-Nov, dry at room temperature
Recommended propagules:	Rhizomes
Site seeding potential:	Low

SUBMERGED AQUATIC PLANTS

For all plants

Recommended propagules:	Plugs
Site seeding potential:	Low

Zostera marina (eelgrass, wrackgrass)

Geographic range:	Alaska to California, Maine to North Carolina
Habitats:	Saltwater, standing water (2-6 ft), low intertidal zone
Seed harvest & storage:	Late June in New York

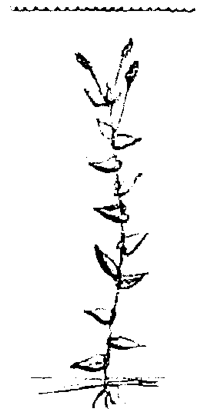
Ruppia maritima (widgeongrass)

Geographic range:	Throughout U.S.
Habitats:	Brackish water, low intertidal zone
Seed harvest & storage:	June till fall

Potamogeton pectinatus (sago pond weed)

Geographic range:	Throughout U.S.
Habitats:	Fresh, alkali and brackish water, standing water (2-6 ft)
Seed harvest & storage:	1-3°C in tapwater
Commercial sources:	5,7,15

Potamogeton perfoliatus (redhead grass)



Geographic range: Northeastern U.S.

Habitats: Brackish water, standing water (2-6 ft)

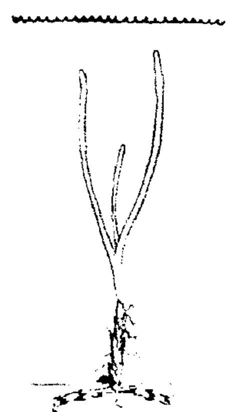
Commercial sources: 15

Vallisnerea americana (wild celery)

Geographic range: Throughout U.S.

Habitats: Fresh and brackish water, shallow water, low intertidal zone

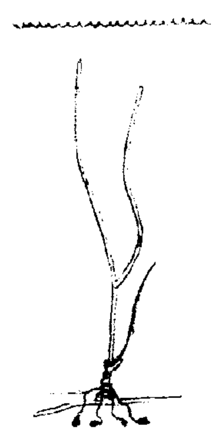
Thalassia testudinum (turtle grass)



Geographic range: Florida to Texas, West Coast

Habitats: Salt water, MLW to 100 ft

Halodule wrightii (shoal grass)



Geographic range: North Carolina and Florida to Texas sparse

Habitats: Salt water

5. Specifications for Wetland Establishment

Contract specifications for any wetland establishment (restoration and replacement) and wetland enhancement measures should include, if applicable:

- a final grading plan,
- final designs of all required structures
- any required construction sequence or time constraints on construction
- requirements for plant materials and their installation,
- requirements for maintenance during the period of establishment.

All of these items are site-specific; thus no two sets of specifications for different projects will be identical. Yet, there are certain specifications that may be generalized in part. These relate to the last two items and will be discussed further. Although no generalizations for the final grading plan can be given, this item requires further discussion because of its importance.

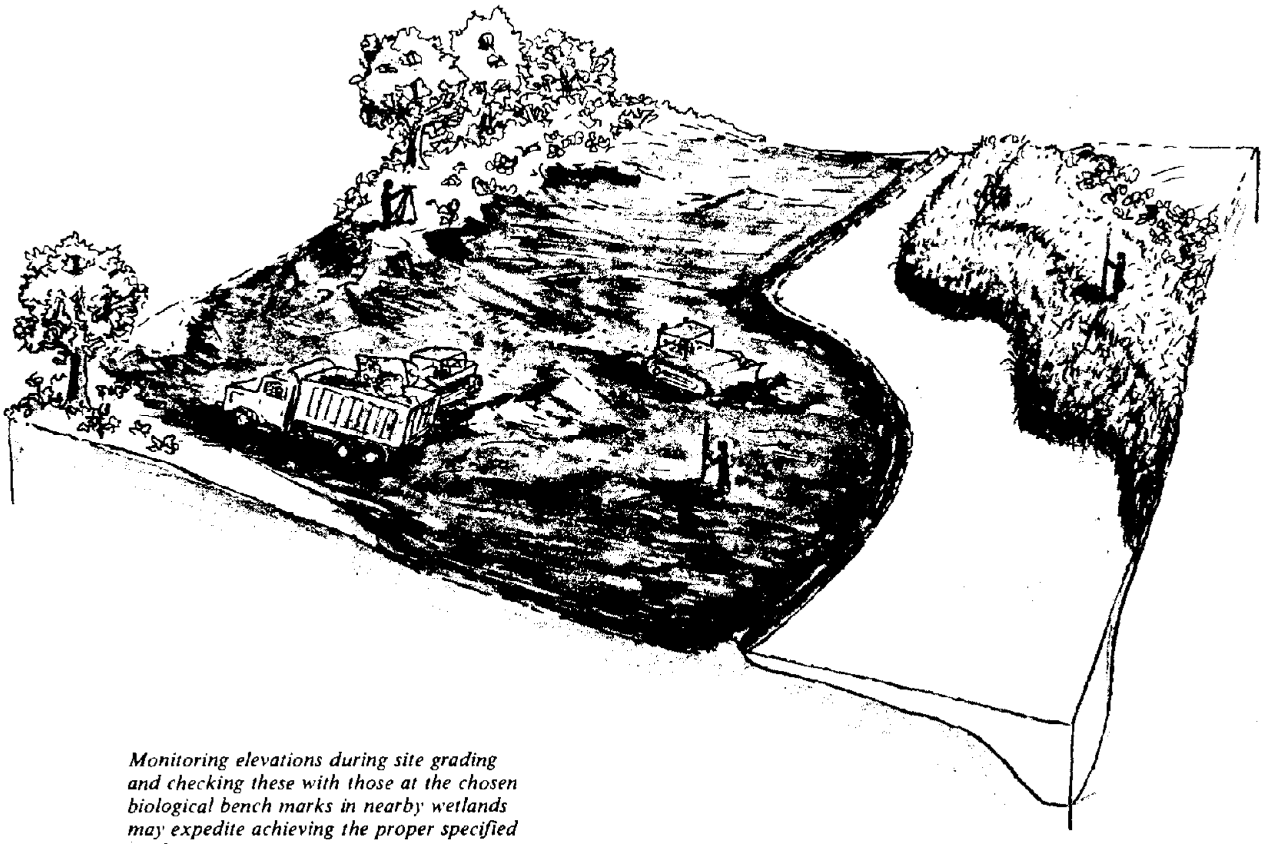
5.1 Final Grading

The final grade of a site and the plant species assigned to the various elevation zones will dictate the ultimate success of a project. Achieving the specified final grades would appear fairly routine, but frequently, this develops into a problem in the preparation of a site. The problem is most likely to arise when the contractor and the inspectors for the contract are not sensitized to the importance of the final grades.

Elevations should be monitored continually during final grading. Where final elevations are designed to correspond to those of nearby wetland communities, it is often convenient to use these communities as biological bench marks for final grade acceptability.

For tidal wetlands, the tolerance (the allowable elevation range) in the final grade increases with increasing tidal range (see Table 1). Numerical values of tolerances for all wetland types are best derived from field measurements of the elevation range associated with the vegetative community to be established. If possible, such measurements should be made in nearby wetlands that are connected to the same water source that will serve the new wetland. For wetland systems having the high water level controlled by an adjustable weir, the final grade may not be so critical.

Developing the final grading plan for wetlands proposed in areas where the only water source is ground water and/or storm runoff is the most difficult. In such areas, seasonal variations in rainfall provide uncertainties in designed water levels.



Monitoring elevations during site grading and checking these with those at the chosen biological bench marks in nearby wetlands may expedite achieving the proper specified grade.

Table 1. Elevation tolerances of hypothetical wetland communities are shown as a function of tidal range. The elevation range for community-1 is MT to MHW. The elevation range for community-2 is MHW to Spring Tide. Mean Low Water is taken as zero.

Tidal Range (ft)		Elevation Tolerance (ft)	Elevation Tolerance (ft)
Mean	Spring	Community-1	Community-2
20	22.8	10-20	20-22.8
10	11.5	5-10	10-11.5
5	6	2.5-5	5-6
3	3.6	1.5-3	3-3.6
1	1.2	0.5-1	1-1.2

5.1.1 **Substrate.** Topsoiling or loaming a wetland site normally is not required; however, upland slopes associated with the site should be treated using regional USDA Soil Conservation Service specifications. The following specification for acceptable wetland substrate characteristics is recommended:

> Following final grade, the substrate shall consist of a minimum of one foot in depth of clean inorganic/organic materials of which 80-90% by weight pass a No. 10 sieve.

Construction rubble and sediments coarser than sand are excluded by this specification. Most borrow and dredged fill materials would be acceptable as would most substrates encountered after excavation. Although integrated (undisrupted) peat is not a desirable substrate, it is acceptable.

Because the annual belowground production of many perennial wetland plants is 40%-60% of the total production, organic buildup in the substrate takes place rapidly. After several years of uniform vegetative cover, the once inorganic substrate will be largely peat or rich in organic content.

5.2 Plant Species

Wetland compensation and enhancement measures have to be successful to achieve appropriate mitigation. For all wetland categories the following landscaping recommendations are provided:

- Use a minimum of plant species adaptable to the various elevation zones—diversification will occur naturally.
- Select herbaceous plant species of potential fish and wildlife and rapid substrate stabilization values for initial establishment.
- Phase the establishment of woody species to follow that of the herbaceous ones.
- Select mostly perennial plant species.
- Select plant species that are adaptable to the broadest tidal range or depth of water range.
- Select endemic species.
- Give priority to commercially available species and/or ones that have been used successfully in the past.
- Do not commit significant areas of the site to species that have questionable potential for successful establishment.
- Avoid specifying only those species that are foraged by wildlife populations expected to utilize the site.

5.3 Plant Propagules

For any project, the selection and specifications of plant propagules to be used will depend upon various factors. These may include:

- timing
- plant species specified
- exposure of the site to waves and currents
- cost
- depth of water
- water and substrate salinities
- availability of different types of propagules
- importance of success.

Generalizations regarding some of the aforementioned factors are given in Tables 2—5.

Table 2. Recommended time of planting and propagule type.

Propagule	Time: Spring	Summer	Fall	Winter
Seed	•			•[a]
Dormant (sprig, bulb, rhizome, tuber)	•			•
Growing (sprig, bulb, rhizome, tuber)	•	•[b]		
Plug or peat-potted nursery stock	•	•	•	•

a) Seeds may after-ripen in the ground at the site; however, bird consumption and erosion may lead to seed loss. b) Transplant mortality rates may be high. Clipping aboveground parts to 6-12 inches in length may reduce the shock of processing, planting, and increase survival.

Table 3. Recommended propagule for site exposure to waves and currents.

Propagule	Exposure of Site to Waves and Currents: High	Moderate	Negligible
Seed			•
Dormant or growing (sprig, bulb, rhizome, tuber)		•	•
Plug or peat-potted nursery stock	•	•	•

Table 4. Relative costs of various propagules.

Propagule	Relative Costs/Planting Unit 1	2	4	6	8	10	12	14	16	18	20
Seed[a]	—										
Sprigs[b]		—									
Bulbs, rhizomes, tubers[c]			—	—	—	—	—				
Plugs or peat-potted nursery stock[c]					—	—	—	—	—	—	—

a) 10 viable seeds per planting unit. b) three sprigs per planting unit.
c) one per planting unit.

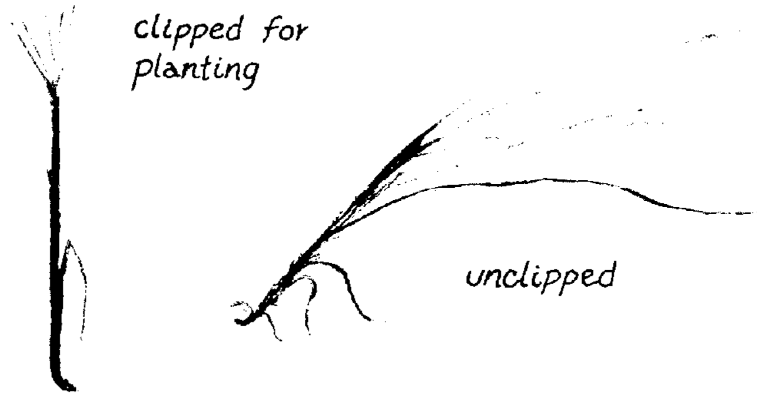
Table 5. Recommended propagules for different depths of water.

Propagule	Depth of Water (tidal or standing) 0-3 in.	Greater than 3 in.
Seed	•	
Sprigs, bulbs, rhizomes, tubers	•	•
Plugs or peat-potted nurery stock	•	•

5.3.1 **Seeds.** Recommended specifications for seed storage are given in Section 4.

Many wetland plant seeds are best stored wet under refrigeration. It is difficult to distribute wet seeds either by hand or mechanically, because the seeds tend to clump together. Several approaches have been used to facilitate the uniform distribution of wet-stored seeds during the seeding operation. These include mixing the wet seeds with just enough clay-based cat litter, dry sand, or other inactive drying agent to provide de-clumping of the seeds and suitable flow of the seed-carrier mix for distribution. Seeds may be so treated on-site just before seeding or shipped from the supplier in the treated state. Large seeds that are planted individually (e.g., arrow arum and mangrove) should not be pre-dried.

Small seeds such as *Typha* spp., *Sagittaria* spp., *Eleocharis* spp., *Salicornia* spp., and *Spartina patens* should not be specified for use unless the site substrate is muddy and the seeds can be surface sown and lightly pressed into the mud to prevent washing out.



*Typical sprig of American Beachgrass (*Ammophila breviligulata*) derived from the wild or from a nursery.*

*Typical bulb and associated new growth of pickerelweed (*Pontederia cordata*) derived from the wild or from a nursery.*

5.3.2. **Sprigs.** This propagule consists of a single stem (culm) of grasses or sedges and associated roots, basal shoots (originating from the base of the stem) and any short rhizome sections left intact. Old or new top growth should be clipped to 6-12 inches in length.

The roots of many herbaceous perennial plants are annual. When sprigs are excavated during the dormant season, the old roots may be stripped from the stems for ease of packaging. However, when new growth sets in, new roots develop. These generally are white and clearly distinguishable from the dark colored inactive roots of the previous growing season. It is the disruption of these new roots through excavation, handling, and transplanting that reduces the success of transplanting sprigs during the active growing season.

5.3.3 **Bulbs, Tubers, and Rhizomes.** These are the underground propagules of perennial plants. They are best excavated and transplanted while in a dormant condition (winter and early spring). However, they can be handled successfully while growing if care is exercised. When these propagules or sections of them are viable, they will exhibit associated light-colored buds or shoots. Bulbs and tubers will be hard and rhizomes resilient when viable.

5.3.4 **Plugs and Peat-potted Nursery Stock.** Plugs are cubical or cylindrical extracts from dense stands of wetland plants. They contain stems, roots, underground perennial parts, and associated substrate. The diameter and depth necessary for an acceptable transplant unit vary with the plant species. Generally, the larger the size of the plug the better. If too small, the critical belowground perennial parts may be fractured. At least 4-inch plugs (width and depth) are recommended for grasses, rushes, and sedges.

Typical plug of a wetland plant.

Peat-potted nursery stocks are commercial peat pots that have been filled with sand or other potting mixtures and sprigged or seeded. Plants are cultivated with pots immersed in water until such time as the plants are well-developed with the root mass extending through all sides of the pot. For salt marsh species, sodium chloride is added to the water until the desired salinity is achieved. Water salinity is controlled by adding freshwater to maintain the water level in the growing compartment.

Below are typical specifications for peat-potted nursery stock of grasses, sedges, and rushes (seedlings or sprigs): all plant materials should originate from within a 100-mile radius of the project site (if such is known to be important) and should be contained in 1-¾-inch to 2-¼-inch pots. Each pot should contain at least 4 (four) stems having a minimum of 6 (six) inches of active growth. Roots should be sufficiently well-developed through the peat pot surfaces so that the plants are firmly contained in the pot.

*Typical peat-potted transplant of Saltmarsh Cordgrass (*Spartina alterniflora*).*

5.4 Planting

In tidal areas, planting should be coordinated with the tides and all planting operations should be completed prior to tidal flooding. If possible, non-tidal areas should be drained prior to planting.

5.4.1 **Seeding.** Seed should be broadcast uniformly over the substrate surface at a rate of 10 viable seeds per square foot. The seeds should be cultivated to subsurface depths of 0 to 1 inch followed by packing, rolling, or dragging the tilled substrate, and for non-tidal projects, the seeded area should be kept moist or flooded by 0 to 2 inches of water until seeds germinate and the seedlings are several inches tall. At this time, the area should be fertilized with standard 10.10.10 or 20.10.10 fertilizer at a rate of 600 lb/acre or 300 lb/acre, respectively. Tidal seeded areas should be fertilized at the above rate when the seedlings are several inches tall and during the fall of the tide (ebb) as water becomes drained from the surface. The water level in non-tidal projects should be maintained well below the top growth of the seedlings during the course of their development. Fertilization should be repeated at the above rate one month following the initial fertilization.

Large seeds (e.g., arrow arum and mangroves) should be treated as transplants.

5.4.2 **Transplanting.** Dividing the area to be transplanted by the square of the distance (D) between transplants gives the number (N) of transplants required ($N = Area/D^2$):

D (ft)	N/Acre
1	43,560
1.5	19,360
2	10,890
3	4,480
4	2,723

Whereas, selecting the largest distance between transplants will provide the lowest cost for the vegetative work, it has distinct disadvantages. Wildlife are attracted to individual clumps of vegetation, and the more rapidly uniform ground cover can be realized the less likely that the area will become denuded by wildlife depredation. Substrate erosion will not become maximally controlled until a uniform vegetative cover is achieved. The function of a wetland to control water quality is also proportional to the percentage of ground cover.

Generally it is advisable to specify a transplant grid that will provide uniform vegetative cover within one full growing season. For most emergent herbaceous plant species, transplanting on a 2-foot grid will achieve this objective. Because of the relatively high cost of planting underwater, the transplant grid for submergent plant species might be increased to 3 to 6 feet.

Side-dress fertilization (placing fertilizer together with the transplant in the substrate) with a controlled release fertilizer is recommended at the time of planting and at the following rates: (Table 6):

Table 6. Fertilization Rates

Propagule	Time	Fertilizer and Rate
peat-pot, plug, tuber, bulb	winter, fall	1 fluid ounce (ca. 30g) Osmocote® 18-5-11 (12- to 14-month release)
	spring	1 fluid ounce (ca. 30g) Osmocote® 18-6-12 (8- to 9-month release)
	summer	1 fluid ounce (ca. 30g) Osmocote® 19-6-12 (3- to 4-month release)
sprig, rhizome		same as above, except ½ fluid ounce

Osmocote® is a controlled release fertilizer that performs well in saline waters and under conditions of saturated substrates. For planting underwater, it is suggested that burlap sacks containing this fertilizer be placed beneath the transplant.

Where the use of Osmocote® or other controlled release fertilizer is impracticable or when mechanical equipment is used which is not designed to simultaneously place plants and fertilizer in the substrate, conventional 10.10.10 (20.10.10) fertilizer may be used. This fertilizer may be applied to the base of the transplant after new growth appears and twice again at one month intervals using the rate of 20g (10g for 20.10.10) per transplant. Such applications should be made when no water will be covering the substrate for 4 (four) hours or more.

Transplants and controlled release fertilizer should be placed in furrows or holes (generally developed mechanically) and covered with 1 (one) to 2 (two) inches of substrate. In high energy sites where erosion is probable and for high salinity substrates (see later), transplants should be placed at subsurface depths of 3 (three) to 4 (four) inches.

5.5 Period of Establishment

Few wetland establishment projects will develop to be totally successful after the seeds or plants are in the ground. Seeding success may be spotty. Transplant mortalities will invariably occur. Litter and debris deposits may bury planted areas. Animal depredation may be significant. In populated areas, vandalism is common. Transplants and seedlings may be washed out by waves and storm runoff flows. Ice may remove transplants. Salt buildup in the substrate may limit plant establishment.

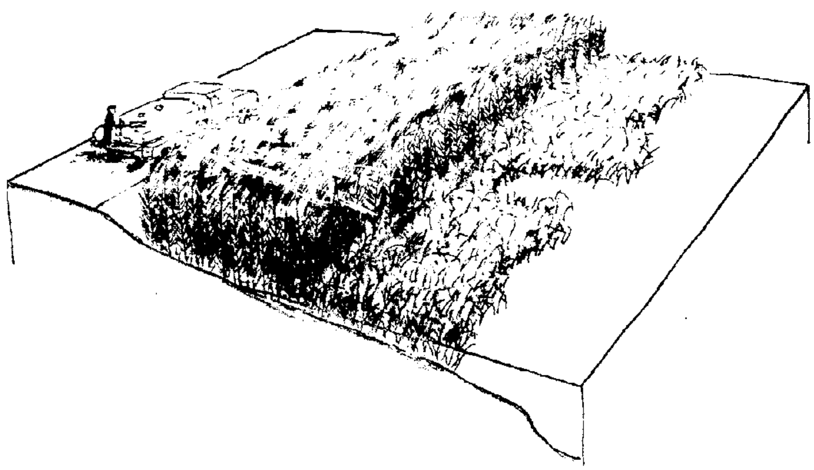
The landscape contract should specify a period of establishment program. Such a program might include monthly site inspections for a full growing season (May—October in most parts of the country) and at the beginning of the second full growing season. For example, if a site was planted in July, maintenance inspections should be required in August-October, May-October of the next year, and May of the following year.

During the monthly maintenance inspections the landscape contractor should be required to (1) transplant all unsuccessful seeded areas to non-seed propagules; (2) replant all transplants that have suffered mortalities or are otherwise gone; (3) remove all litter and debris deposits throughout the site; (4) conduct the specified fertilizations; and (5) take any specified measures to temporarily exclude wildlife.

Requiring a period of establishment section to the landscape contract will guarantee the success of the project.

Wetland establishment work is not common. The uncertainties regarding success are much greater than those of landscaping a highway median. It is important, therefore, that the appropriate highway department personnel and the contract inspectors be aware of potential problems and be receptive to contract change orders to resolve any problems that may arise and that clearly are outside the control of the landscape contractor. Such problems may relate to poor design or improper site preparation, plant species designated for improper elevations, or water level controls that are inadequate. They may relate to unexpected wildlife depredation or unavoidable increases in substrate salinities or to an untimely storm or to high water turbidity.

Experience indicates that many regulatory and consulting resource agencies may accept seeding or transplanting success rates of 85% per unit area, as determined at the beginning of the second growing season.



Selected removal of Phragmites australis *and replacement with a more desirable plant species might be considered as part of an enhancement component of a mitigation plan.*

5.6 Common Reed Control

Common reed (*Phragmites australis*) is a cosmopolitan and ubiquitous perennial plant that may spread 10-29 feet during a growing season by stolons or several feet by rhizomes. In saltwater (greater than 20 ppt salt) the plant develops mostly above the high water line; however, in freshwater areas the plant may be rooted in the tidal zone or below the water level. Its density, height (6-15 ft), and high productivity often preclude associations with other plant species and stands of *P. australis* frequently are monotypic.

Phragmites australis has some value to wildlife as a cover and nesting habitat. Muskrats prefer to consume the rhizomes of the plant over those of smooth cordgrass *(Spartina alterniflora).* The plant has positive erosion control potential, and when growing in the water, it has a positive potential for controlling water quality.

The standing crop of *P. australis* does not turn over (cycle) rapidly. The dried out dead aboveground parts may stand erect for one or more years and present serious fire hazards. Other vegetation that is adaptable to the same habitat may be preferred for fish and wildlife purposes. Because most wildlife biologists consider *P. australis* to be an undesirable weed, consideration should be given to selected removal of the species, should it dominate, and to replacement with more desirable ones as part of the enhancement component of the mitigation plan.

Successful control of *P. australis* by the use of physical methods is not feasible. Mowing, plowing, disking, and burning facilitate the spread and propagation of the species. The herbicide Roundup® is to date the most effective control of the species. One application of this herbicide is sufficient for eradication. Reportedly, it biodegrades within days after application and is safe for use in aquatic environments. Dowpon® is another effective herbicide; however, it usually must be applied twice in successive years for total control.

To control *P. australis,* mist spray the foliage with a mixture of 2 (two) quarts of Roundup® in 25 gallons of water per acre or 40 (forty) pounds of Dowpon® in 200 gallons of water per acre, from the top downward at the time of or just following flowering (in August-September) and at least 8 hours prior to probable precipitation.

Two weeks following treatment with Roundup®, the aboveground crop of *P. australis* may be burned or mowed and the area revegetated with a more desirable species. When Dowpon® is used, two successive annual applications should be planned with any revegetation taking place no sooner than 30 days following the last application.

Permits may be required for the use of these herbicides in aquatic environments. State water resource agencies should be contacted to determine any restriction of their use.

Both Roundup® and Dowpon® will destroy other plant species that they contact. Consequently, care is necessary to avoid spraying wetland vegetation outside the limits of the *P. australis.* In tidal areas, it may be advisable to restrict spraying to times of one hour before to one hour after scheduled high tide for the area. Under these conditions, much of the wetland foliage will be under water and protected.

5.7 Costs

The costs associated with (1) planning and design, (2) obtaining the site, (3) preparing the site, (4) constructing any necessary structures, (5) planting the site, and (6) maintaining the site during the period of establishment comprise the total cost of the wetland establishment. The costs of items 1-4 are routinely estimated by the real estate, landscape, and engineering personnel associated with the project.

The costs for planting and for the period of establishment often vary and depend upon site conditions. Table 7 provides rough estimates of material and labor costs for these items when site conditions exist that would not limit the rate and mechanism of installing the plant materials.

Table 7. Rough estimates of costs for vegetative establishment.

Work Item	Unit $ Cost (1981)	Per Acre $ Cost (1981)	Notes
Plant Materials (FOB origin)			
a) Sprigs	0.15	1,634	2-ft grid; one unit/hill
b) Tubers, rhizomes, bulbs	0.25	2,723	2-ft grid; one unit/hill
c) Potted plants	0.50	5,445	2-ft grid; one unit/hill
d) Plugs	0.55	5,990	2-ft grid; one unit/hill
e) Seed	----	1,000	cost includes collecting, threshing cleaning, and cold storing ca. 500,000 seeds per acre
Fertilizer			
a) Controlled release	0.85 lb	815	2-ft grid, side-dressed at time of planting with 40g/hill
b) 10.10.10	0.20 lb	240	2 applications at a rate of 600 lb/acre for each
Labor			
a) Seeding	----	4 person-hours	broadcast seed plus cultivation
b) Transplanting	----	64 person-hours	2-ft grid using a mechanical auger to drill holes. A fully mechanical operation will require approximately one-half the time.
c) Fertilization (side-dress or surface applied)	----	16 person-hours	2-ft grid, each transplant at the time of planting
d) Fertilization (surface broadcasting)	----	2 person-hours	post-planting
Period of Establishment	----	96 person-hours/year	monthly maintenance work during May through October. For materials estimate, assume that 20% of the site will have to be revegetated due to transplant mortalities or unsuccessful seeding results.

Some items that will add cost to the estimate are:

- lack of direct accessibility to the site
- inability to use conventional equipment
- planting under water
- profit
- overhead (including bonding and insurance)
- down time due to weather and water level or tide conditions
- equipment (tractor, cultivation, mechanical planting)
- per diem
- guarantee (in addition to the period of maintenance)
- union labor required (or the payment of prevailing wages plus benefits).

Generally, the larger the project the lower will be the per acre cost. Material costs will be discounted and mobilization costs will comprise a smaller percentage of the total cost.

6. Factors Limiting Success

Factors that have been found to limit the success of wetland establishment projects are:

- improper final grade
- improper wetland plant species
- restricted tidal flow to site or inadequate water level control
- improper timing for incorporation of the specified plant materials
- erosion
- landscape contractor (poor labor and/or plant materials)
- vandalism
- depredation by wildlife and livestock
- development of a salt stress zone
- litter deposition and accumulation.

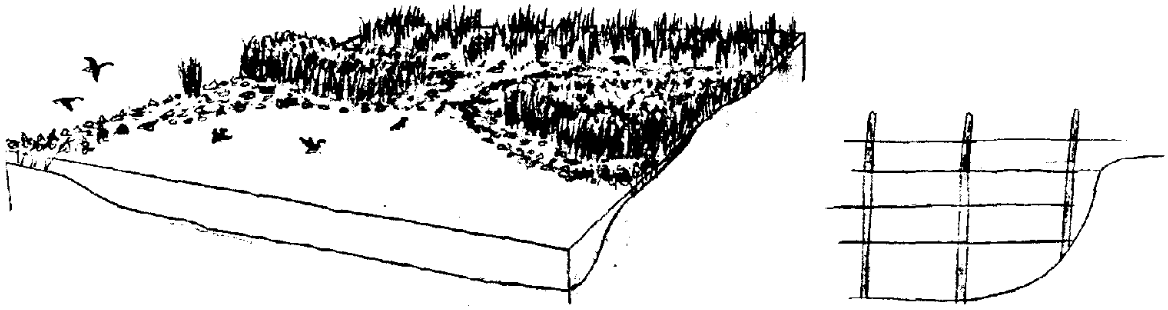
Most of these factors have been mentioned previously. The first six may be traced to imperfections in project design, specifications, execution, and/or inspection (control).

Vandalism usually consists of the pulling out of transplants and the destruction of fences. It is most likely to occur in highly populated areas. There is no ready control of vandalism; however, local police should be notified and possibly signs should be erected.

If regional populations of migratory or resident geese and brant are known to be high and if there is evidence in the area of wildlife or livestock foraging in wetlands, the new wetland area may have to be enclosed by a fence to temporarily exclude these animals. Animals are drawn to isolated clumps of vegetation, and a newly planted area is more vulnerable to depredation than one that is uniformly vegetated by mature and well-established plants. Consequently, such protection may be required for about two years.

Geese normally do not alight in tall stands of vegetation. They alight in open water and then swim into a wetland, feeding on the wetland edge and working landward. Protecting this edge often will be sufficient to protect the wetland. A fence along the seaward edge of the vegetation, that consists of posts connected by nylon line (ca. 1/8") rails spaced every 6 (six) inches from 6 (six) inches above the low water to 6 (six) inches above the high water elevations, has been found to be effective in exluding geese from new wetland areas. Such a fence is inexpensive and can be rapidly installed and easily maintained.

In the development of new salt marshes, the area from Mean High Water up to the one-year storm water elevation may develop into a salt stress zone where vegetative establishment is severely limited. The problem arises because much of this zone is flooded several times monthly by spring tides and the balance of it is flooded occasionally by storm tides. During the time between flooding, evaporation of water leads to increases in substrate sal-

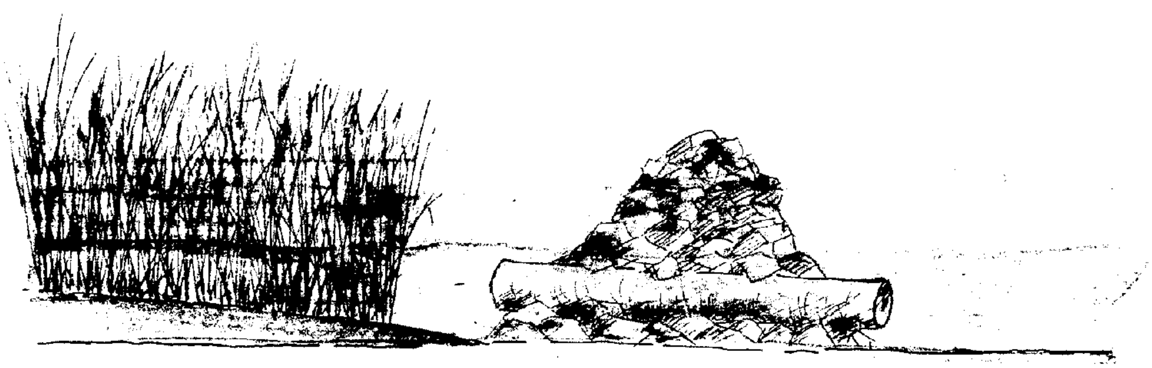


A site may be protected against waterfowl depredation by installating an inexpensive nylon line fence. More substantial fences may have to be used to exclude larger animals.

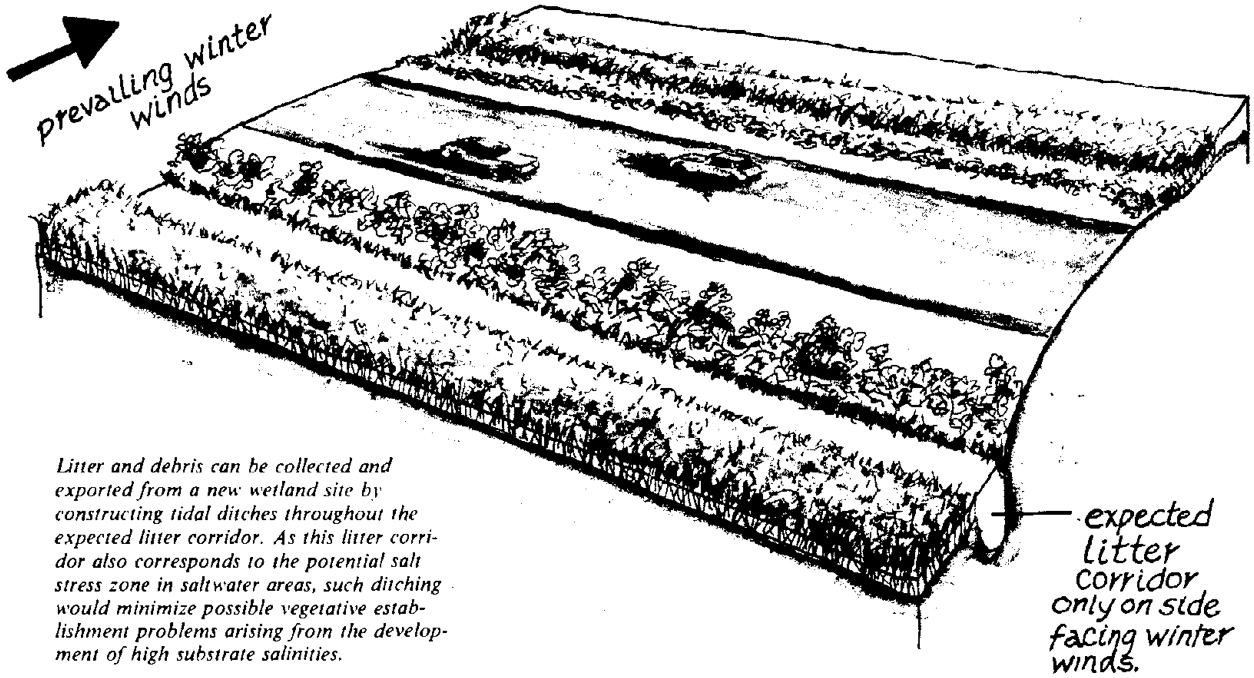
inites. As this occasional flooding by saltwater repeats, salt concentration in the substrate may build up at a more rapid rate than that of salt leaching by rain. In such instances substrate salinities may develop that are toxic to transplants of salt marsh vegetation.[1]

A salt stress zone is most likely to develop when (1) water salinities exceed 10 parts per thousand, (2) salt marsh as opposed to upland surrounds the new wetland, and (3) the substrate is sandy as opposed to muddy or peaty. Vegetative establishment throughout the salt stress zone is facilitated by (1) transplanting as opposed to seeding, (2) preventing saltwater inundation until the transplants are established or transplanting vegetation before the substrate becomes contaminated by salt, (3) planting deep (5-6 inches) in order to introduce transplants to lower salinity substrates (substrate salinity decreases with increasing depth), and (4) conditioning the plant materials to increasing water salinities (up to 35 parts per thousand maximum) prior to transplanting. If transplants throughout the salt stress zone are alive and growing 30 days after planting, further buildup of salt in the substrate will retard plant productivity and the rate of vegetative spread, but normally will not lead to transplant mortality.

[1]If the conductivity of the supernatant liquid after one part of ovendry substrate (3-inch deep sample) is thoroughly mixed with two parts of distilled water at 72° F is 3,000 micromhos or greater, vegetative establishment may not be possible.



Floating litter and debris can be exluded from a new wetland site.



Litter and debris can be collected and exported from a new wetland site by constructing tidal ditches throughout the expected litter corridor. As this litter corridor also corresponds to the potential salt stress zone in saltwater areas, such ditching would minimize possible vegetative establishment problems arising from the development of high substrate salinities.

The deposition and accumulation of litter and debris throughout wetland areas may be a perennial problem, especially in industrialized and highly populated areas. The period of establishment program will temporarily take care of this problem; however, if the problem is expected to be potentially serious, a wetland should be designed that is relatively maintenance free. Two general solutions to this problem are to (1) exclude litter from the site and (2) collect, and export litter from the site.

Permanently excluding most litter and debris from a new wetland area may require the construction of a low profile bulkhead or stone revetment along the seaward edge of the project. The structure need only be constructed to such a height that during average conditions water does not overtop it. Culverts passing through the structure to permit unrestricted flow of water to and from the wetland should have the seaward ends below water under normal conditions in order to prevent the entry of floating materials.

An alternative method to prevent the accumulation of litter and debris in tidal wetland areas is to construct a tidal ditch throughout the litter corridor (in salt marsh areas this corridor also corresponds to the potential salt stress zone). Such a ditch will collect litter and debris during flood tides and export some of these materials during the ebb tide. Materials that are not exported will be contained in the environs of the ditch and will be subject to more rapid decomposition than if the materials were deposited throughout drier elevations of the site.

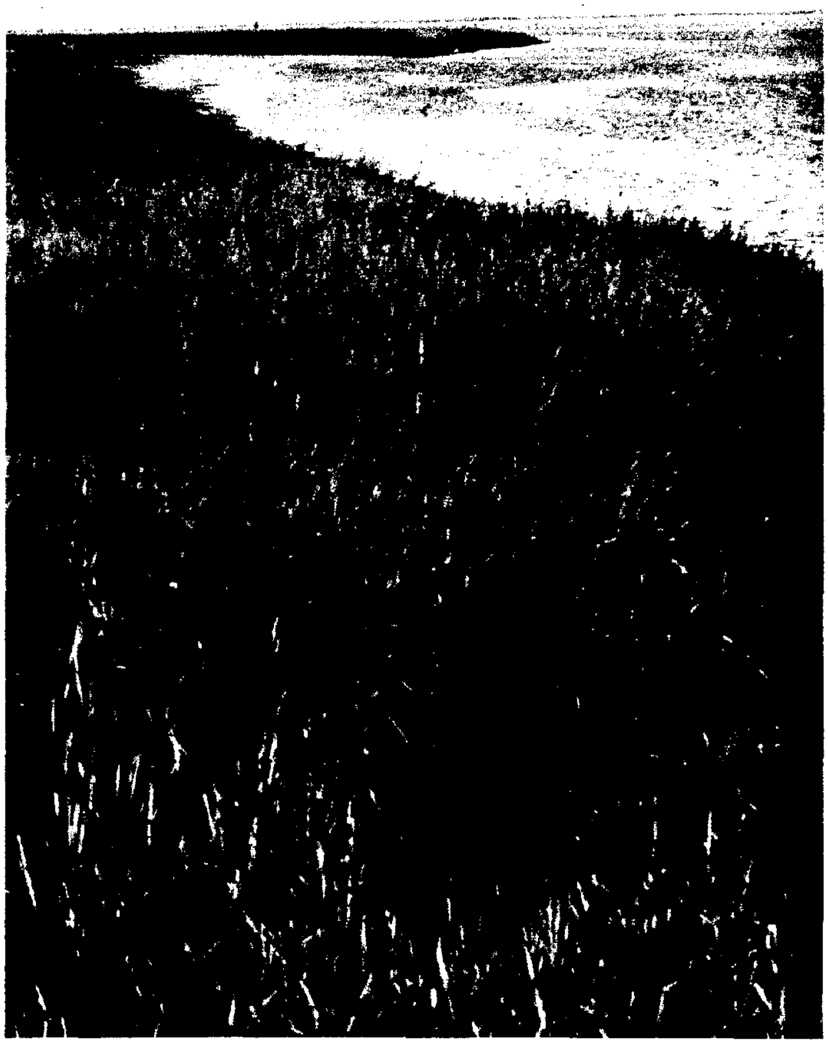
In addition to performing this practical function, the introduction of tidal ditches in a new wetland area will (1) facilitate water flow and nutrient exchange throughout the wetland, (2) increase the habitat diversity through providing an increased edge effect, and (3) minimize the successful breeding of mosquitoes through facilitating the drainage of the site and importing fish that feed on mosquito larvae.

7. Summary

Most construction in wetlands is regulated by federal and state laws. The unavoidable involvement of wetlands by a proposed construction activity may be permitted provided that (1) such construction is judged to be in the public interest and (2) an acceptable plan to mitigate wetland losses is proposed by the applicant. A central component of the mitigation plan is compensating (offsetting) unavoidable wetland losses.

This manual reviews conceptual alternatives for compensating unavoidable wetland losses by proposed highway projects. Because most compensation measures involve wetland establishment the manual describes the known techniques for establishing wetlands as well as the factors that may limit success. It also provides general specifications and costs for wetland establishment.

A separate section on Target Perennial Wetland Plants is provided to assist the landscape design of proposed compensation measures. This section initiates the more technical and less qualitative half of the manual. This and later sections are intended to be utilized primarily by the technical personnel of state departments of transportation. Earlier sections of the manual are more qualitative and graphical and are intended to be meaningful to all personnel of state departments of transportation.



Appendix A

Commercial Sources for Plant Materials [a]

1. Environmental Concern Inc., P.O. Box P, St. Michaels, MD 21663
2. Gardens of the Blue Ridge, P.O. Box 10, Pineola, NC 28662
3. Horizon Seed Co., 1540 Cornhusker Highway, Lincoln, NB 68500
4. Horticultural Systems, Inc., P.O. Box 70, Parrish, FL 33564
5. Kesters Wild Game Food Nurseries, Inc., P.O. Box V, Omro, WI 54963
6. Lilypons Water Gardens, Lilypons, MD 21717
7. Mangelsdorf Seed Co., P.O. Box 327, St. Louis, MO 63166
8. Mangrove Systems, Inc. 504 S. Brevard Avenue, Tampa, FL 33606
9. San Francisco Bay Marine Research Center, 8 Middle Road, Lafayette, CA 94549
10. Sharp Bros. Seed Co., Healy, KS 67850
11. Slocum Water Gardens, 1101 Cypress Gardens Road, Winter Haven, FL 33880
12. Stanford Seed Co., 809 N. Bethlehem Pike, Spring House, PA 19477
13. Stock Seed Farms, Inc. R.R. Box 112, Murdock, NB 68407
14. Van Ness Water Gardens, 2460 Euclid Avenue, Upland, CA 91786
15. Wildlife Nurseries, P.O. Box 2724, Oshkosh, WI 54901
16. Wm. Tricker, Inc., 74 Allendale Avenue, Saddle River, NJ 07458

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a) The listed sources may not include all existing ones; however, an effort was made to include all known sources at the time of writing.

Appendix B

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Listed in this bibliography under topical headings are recommended readings and source-materials.

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