GUIDELINES for ENHANCEMENT and RESTORATION of

DIKED HISTORIC BAYLANDS

By

H. Thomas Harvey, Ph.D.,
Harvey and Stanley Associates, Inc.

Philip Williams, Ph.D., P.E. and
Jeffrey Haltiner, P.E.,
Philip Williams and Associates

Madrone Associates

and

Staff of the
San Francisco Bay Conservation
and Development Commission

Revised FEBRUARY 1983

A Technical Report Prepared for

SAN FRANCISCO BAY CONSERVATION AND DEVELOPMENT COMMISSION

GUIDELINES FOR ENHANCEMENT AND RESTORATION OF DIKED HISTORIC BAYLANDS

A Technical Report
by

H. Thomas Harvey, Ph.D., Harvey and Stanley Associates

Philip Williams, Ph.D., P. E. and Jeffrey Haltiner, P.E.,
Philip Williams and Associates

Madrone Associates

and

Staff of the San Francisco Bay Conservation
and Development Commission

This publication was prepared with financial assistance from the Office of Coastal Zone Management, National Oceanic and Atmospheric Administration, under the provisions of the Federal Coastal Zone Management Act of 1972, as amended.

Prepared for the
San Francisco Bay Conservation and Development Commission
As Part of the BCDC Diked Historic Baylands Study

April, 1982

SAN FRANCISCO BAY CONSERVATION AND DEVELOPMENT COMMISSION
Thirty Van Ness Avenue, San Francisco 94102 557 - 3686

November 26, 1986

INFORMATION REGARDING OFFICE OF ADMINISTRATIVE LAW DETERMINATION CONCERNING THE COMMISSION'S DIKED HISTORIC BAYLANDS REPORT

On September 3, 1986, the Office of Administrative Law (OAL) ruled that with two minor exceptions, the Commission's Diked Historic Baylands of San Francisco Bay.....Findings, Policies, and Maps (October 21, 1982) (Diked Historic Baylands Plan) does not constitute a regulation under the Administrative Procedures Act (APA). The decision responded to a request from the Bay Planning Coalition to determine if the Commission had acted illegally when it had adopted the Diked Historic Baylands Plan without following the APA.

The two minor exceptions concern the two policies located at the bottom of page six of the Diked Historic Baylands Plan, which deal with development within diked historic baylands that are located partly within the Commission's permit jurisdiction. These two policies essentially indicate that such development should be permitted only if it is consistent with all applicable policies contained in the McAteer-Petris Act and the San Francisco Bay Plan and only if all wildlife values lost or threatened by such development will be fully mitigated. OAL concluded that unlike all the other policies contained in the Diked Historic Baylands Plan, which are only advisory because they apply only to areas outside the Commission's permit jurisdiction, these two policies are regulations because they deal with activities located within the Commission's permit jurisdiction and are therefore enforceable through the Commission's permit process. OAL further concluded that the existence of separate Commission mitigation policies in the San Francisco Bay Plan does not render the possible use and application of the mitigation policies in the Diked Historic Baylands Plan moot.

The Commission acknowledges that the language of the the mitigation policies contained in the Diked Historic Baylands Plan differs from the language of the mitigation policies contained in the Bay Plan. Nevertheless, the Commission believes that the existence of the mitigation policies in the Diked Historic Baylands Plan is irrelevant because the application of either sets of mitigation policies would result in the application of identical mitigation conditions to any given set of facts. Moreover, the Commission believes and fully acknowledges that the Commission must use only the mitigation policies contained in the San Francisco Bay Plan when it reviews permit applications for projects within its McAteer-Petris Act jurisdiction.

This technical report, by the Staff of the
San Francisco Bay Conservation and Development Commission,
was prepared as part of the Diked Historic Baylands Study.
The report provides guidelines for site selection and designing
restoration and enhancement projects for wetlands.
This technical report should be read in
conjunction with the staff report entitled
"Diked Historic Baylands of San Francisco Bay."

TABLE OF CONTENTS

ILLUSTRATIONS

INTRODUCTION

Although many enhancement and restoration projects have been undertaken in the Bay Area in the last few years, there is little published information about how to select sites and plan restoration and enhancement projects. Wetlands enhancement and restoration should create conditions that will be most beneficial to fish and wildlife while avoiding environmental losses and unsuccessful projects.

This technical report provides guidelines for selecting sites and designing restoration and enhancement projects for wetlands. The report is divided into two sections. The first section discusses the regional habitat needs for San Francisco Bay and was prepared by the staff. The second section contains the guidelines for restoration and enhancement. It was prepared by Philip Williams and Associates, Harvey and Stanley Associates, and Madrone Associates. This section is intended to be used by professionals who design and implement marsh restoration and enhancement projects.

SECTION I: REGIONAL HABITAT NEEDS FOR SAN FRANCISCO BAY

The professionals consulted in this study agreed that creation of three specific habitats would improve Bay wildlife resources. They are: (1) habitats in short supply, such as fresh and brackish water marsh; (2) habitat for rare and endangered species, particularly high marsh; and (3) tidal marshes.

Habitats in Short Supply

Diking and filling wetlands around the Bay has severely depleted all types of marshlands. Fresh and brackish water marshes, including the transition zones that separate the marshes from adjacent uplands, have been especially reduced.

1. Freshwater Marsh

The reduction of freshwater inflow and destruction of freshwater wetlands through diking, draining, filling, and development have eliminated nearly all of the natural freshwater marshes once present around San Francisco Bay. The South Bay at one time supported several thousand acres of freshwater marsh. Today the only freshwater marsh in the South Bay is at Coyote Hills Regional Park, and it is only a few acres in size.* The marsh is artificially maintained by urban runoff in winter and by well water in summer. Even with such management, the water in the marsh is somewhat saline.

Freshwater marshes are important because they support a great diversity of plants and animals. Creation of freshwater marshes can enhance the diversity of species at a specific location and also increase the diversity of the Bay system by interspersing tidal with fresher water marshes. This diversity, once quite common around the Bay, has all but disappeared today.

2. Brackish Water Marsh

Many brackish water marshes that occured at the Bay mouths of the Napa River, Guadalupe Creek, Alameda Creek, and Corte Madera Creek have been physically altered or converted to salt marsh by changes to or diversion of freshwater. The North Bay marshes of the Petaluma and Napa Rivers, and Suisun Bay are among the few remaining brackish marshes. There are 1,396 acres of diked brackish water marsh scattered around the Bay. In addition, there are a few scattered brackish marshes elsewhere, for example at the upper ends of slough in the South Bay where salt water is sufficiently diluted by freshwater runoff.

Brackish water marshes are important because they support a variety of vegetation types. A great diversity of aquatic organisms and wildlife species, and breeding populations of birds such as the salt marsh yellowthroat, a potentially threatened species, also use brackish water marshes. Creation of additional brackish habitat would increase the diversity of plants and wildlife around the Bay.

---

*20 acres in summer, 50 acres in winter.

Rare and Endangered Species Habitat

As freshwater and brackish water marshes and their surrounding vegetation have become scarce, so too have many plant and animal species that were once common around the Bay. These include the endangered California Clapper rail, salt marsh harvest mouse, San Francisco garter snake and the rare black rail. Plant species such as birds' beak, marsh gumweed, mudflat quill plant, Marin knotwood, and Suisun thistle are also threatened, rare, or endangered. Brackish marshes and their edges are required by many of the endangered or rare plant species.

Brackish habitats could be created that would benefit these species. For example, high marsh zones around restored tidal marshes could benefit the clapper rail, harvest mouse, and black rail. Freshwater marsh and bordering transition zones could benefit the San Francisco garter snake.

Tidal Marsh Restoration

Diking and filling of historic tidal marshlands have decreased the productivity of the Bay ecosystem because dikes have cut off the source of nutrients and organic material from the Bay itself. The nutrients carried by freshwater runoff and the organic material resulting from decaying marsh vegetation are a food source for Bay dwelling organisms that is not available when tidal exchange and runoff is eliminated.

The productivity of the Bay should increase if diked areas are restored to tidal action because the inflow of organic material should enhance plant growth on newly created tidal mudflats. Plants growing on mudflats would also support small invertebrates and fish. Eventually the numbers of birds, mammals, and other animals that the Bay supports should increase because the food supply has increased.

But if the restoration of diked areas is not carefully planned and executed, none of these benefits will likely occur. Badly managed projects may result only in erosion, increased sedimentation, and turbidity with little increase in wildlife or fish.

Choosing Sites

In creating new habitat, there are three important factors that should always be considered. First, sites with already stable, productive habitats should not be selected for restoration or enhancement. These habitats should be identified by fish and wildlife professionals. Secondly, wherever possible, a restoration or enhancement site should create more than one habitat zone e.g., a gradient from low wet areas to upland dry habitats. This is because such diversity is similar to the historic natural conditions. Thirdly, only native vegetation should be used in marsh restoration or enhancement projects. There are several reasons for this. There is a scientific and aesthetic interest in keeping the natural environment intact. Introduced species can sometimes become a nuisance if there are no checks and balances within the system to control them -- the water hyacinth is a good example. Also, non-native plant species do not always provide the same resource value, i.e. food or shelter, to native wildlife. In general, since introduced species are a less known entity, their use in marsh restoration or enhancement projects should be avoided.

The following engineering, planting, and management guidelines outline the primary factors that must be addressed when designing wetland restoration or enhancement. While specific physical and biological alterations must be determined by the situation at each site, the reader can be aware of typical problems that can result from haphazard or miscalculated projects. Many of the problems from past restoration efforts can be avoided if care is taken in the planning stages to collect all the necessary information and design the restoration accordingly.

The principles given here are those found to be broadly applicable to projects in the Bay Area. The practice of marsh restoration in the Pacific states is still in its infancy, and in many ways our knowledge has not yet caught up with our need to replace lost habitat.

SECTION II: ENHANCEMENT AND RESTORATION OF DIKED HISTORIC BAYLANDS

Restoration or enhancement of a diked wetland requires that many complex design criteria be interrelated. The most effective way of doing this is through the development of a marsh management plan that determines the design, operation, and maintenance demands of the marsh. In developing this plan, three functions or potential functions of the hydrologic system have to be considered:

1. The hydraulic regime (the extent and period of inundation and circulation) needed to restore marsh vegetation;

2. the use of the wetland to improve the quality of stormwater runoff or sewage effluent entering the Bay; and

3. the use of the wetland as a stormwater retention basin for flood control.

These functions are described in the following sections. Much of the information relating to design criteria and requirements is based on observation of actual restoration projects. A summary of restoration projects observed for this report is shown on Table A.

Hydraulic Design for Restoration to Tidal Marsh

1. Tidal Elevation and Marsh Topography

The most important design parameters to consider when reopening diked historic baylands to tidal action are the tidal range and period of inundation of the flat, former marsh plain. Often the level of this surface has subsided several feet because of compaction or oxidation. Such an area, when subject to full tidal action, would be too low for marsh vegetation establishment. Low areas are more suitable for creating open water and mud flats. In other situations, the new level of the marsh plain has been artificially raised by filling or by the deposition of dredge spoils, resulting in excessively high elevations and soil salinity levels that prevent marsh plant survival.

There are two approaches to designing appropriate marsh elevations relative to the tidal range:

a. Modify the Topography. The desired tidal range can be established through topographic modification. The marsh plain should be graded to provide sufficient areas at the appropriate tidal elevations to promote establishment of desired marsh vegetation types. If subsidence has occurred, substantial amounts of suitable fill may have to be placed to raise the elevation. Thereafter, the marsh is subjected to full tidal action by breaching the surrounding levee.

TABLE A

SUMMARY OF SALT MARSH RESTORATION PROJECTS FROM DIKED WETLANDS

Location	Date	Acres	Tidal Range (Elevations Relative to NGVD)	Work Carried Out	Present Use	Remarks	Owner
1. Faber Tract, Palo Alto	1971	95	full	Levee breached, planted	Marsh preserve	Site was used for dredge spoil	Palo Alto
2. Pond 3 Alameda, Newark	1976	110	full	Levee breached, planted	Open space	Site used for dredge spoil/elevations too high in part of site/cordgrass seeding unsuccessful	ACFC & WCD
3. Creekside Park, Larkspur	1976	20	full	Area excavated and recontoured, planted	Park	Non-native marsh plants planted	Marin Co.
4. Muzzi Marsh, Corte Madera	1976	125	full	Levee breached, limited planting of trial plots, second phase to improve circulation & elevations now underway.	Marsh preserve	Site used for dredge spoil, for both retention and to create marsh elevations	CDF & G
5. Mill Valley Middle School, Mill Valley	1976	3	full summer only	Manual slide gate installed	Open space Flood basin		Mill Valley
6. Palo Alto Lagoon, Palo Alto	1977	12	-1 to +2	Constricted culvert installed	Park Pond	Regulated for waterfowl	Palo Alto
7. Johnson Landing, Hayward	1980	230	full (above +1)	Levees breached, channels & islands constructed	Park Marsh preserve	Natural invasion of plants being monitored	EBRPD
8. Doolittle Pond, Oakland	1980	30	full	Diked breached	Open water	Very little marsh in lagoon	Port of Oakland
9. Palo Alto Flood Basin	1982	525	max. -1.5	Automatic slide gate installed	Flood basin	Restoration delayed/ABAG monitoring as part of 208 plan	SCVWD

b. Control the Inundation. If the marsh plain has experienced extensive subsidence or if there are other constraints on the maximum tidal elevation, such as flooding in surrounding areas, tidal elevations can be controlled by an automatic tide gate. This minimizes the topographic change required, and is desirable in areas where the original marsh drainage network still exists and is in the appropriate configuration for proper water exchange. This is often considerably less expensive to build, but requires continued maintenance.

To determine what modifications will be needed to create conditions suitable for marsh plant growth, it is necessary to obtain the following information: (1) projected tidal range for the area; (2) accurate elevations for the area; (3) the location and amount of levee that will be removed or the size and location of the culvert that will be built; (4) the tidal prism and amount of damping (i.e., the amount by which the marsh tidal range is lessened relative to the Bay), if any, to the prism that will occur due to constriction of water entry; (5) the type and coverage of marsh plants desired; and (6) the amount and location of expected sedimentation and erosion.

2. Tidal Range Design

If possible, tide characteristics should be measured at the site and cross-referenced to a nearby National Oceanic and Atmospheric Administration (NOAA) tide gage. If this is not feasible, nearby tidal data can be used and adjusted for any local conditions at the specific site as, would occur for example, if the marsh were at the end of a long narrow channel. A typical design tidal cycle or sequence of cycles should then be developed. For example, a tidal cycle constructed from MHHW, MLLW, MLHW, and MHLW, according to the method outlined in NOAA tide tables (U. S. Department of Commerce NOAA, 1980), would provide a good indication of the range of tidal conditions to be expected.

3. Levee Breach Design

The size of the levee breach or culvert opening affects both circulation and tidal range in the marsh. In general, it is preferable to have as wide an opening as possible. A calculation could be made of the difference between tidal range (water heights) in the Bay and the marsh. This calculation, called a "tidal routing computation,"* is made by estimating the flow through the opening, for successive time increments. With this information, one can develop a tidal cycle inside the marsh for a typical tidal cycle in the Bay.

---

* The flow rate computation through a constricted opening is described in Chow's "Open Channel Hydraulics" (Chow, 1959). In most situations the flow is given by:

$$Q = C \times A\sqrt{2g\Delta h}$$

where C is the coefficient of discharge, usually about 0.7; A is the cross-sectional area of the opening; and Δh is the difference in water elevation inside and outside the levee.

The flow through the opening for a given time increment is added or subtracted to the volume of water in the marsh. Using a volume/depth curve derived from a topographic survey of the marsh, the new water surface elevation in the marsh is estimated.

Using this procedure, the damping of the tidal cycle for a given levee breach width can be estimated. The marsh vegetation species occupy a different range of elevations in a damped tidal cycle than in an unrestricted one. Either the marsh grading plan can be designed for a damped tidal cycle, or the levee breach can be made wide enough so as to cause no significant reduction in tidal range.

A damped tidal cycle will have less circulation than an unrestricted one, and this also may be a limiting parameter.

The procedure described above can also be used to estimate the tidal cycle at the end of a slough within the marsh. However, when the tidal drainage system is complex, the use of a computer model that simulates the flows (such as that designed by Fischer, 1972) is required.

4. Topographic Modifications

The first requirement in designing a grading plan for marsh restoration is an accurate topographic survey. The second is the ability to exert close topographic control on any grading carried out. As was shown in the Alameda Creek marsh restoration, where the original breach eroded and plantings failed to spread, errors in grading of even six inches can greatly affect the type of vegetation ultimately established. Elevation requirements for marsh vegetation are discussed on pages 18 through 20.

Three types of topographic modifications are usually considered:

a. Channels. These can usually be cut with side slopes at the angle of repose except where a deliberate effort is made to create mud flat areas. Experience at the Alameda Creek marsh shows that a major problem is the difficulty of using conventional grading equipment on the soft mud underlying the few feet of more consolidated surface deposits.

b. Marsh Plain. In its natural state the marsh plain is flat and drained by a complex network of tidal drainage channels. If the original marsh plain has remained undisturbed, subsidence has not occurred, or tidal inundation is to be mechanically controlled to the appropriate elevations, then filling is not necessary. If filling is required, however, there are three primary considerations:

- There must be a precise elevation control on the new, graded marsh plain surface;
- a tidal drainage network should also be graded; and
- the fill material should preferably be soft estuarine mud. Other types of fill are generally unsuitable, as can be seen in

some locations at the Creekside Park marsh restoration.* Use of firm or stiff estuarine mud excavated from surrounding areas may cause difficulty for marsh plant restoration due to consolidation (Atwater, pers. comm.).

c. Islands and Dikes. It is usually desirable to create islands or preserve portions of dikes as waterfowl and wildlife habitats. Islands should be designed with minimum elevation at least three feet above the maximum predicted tide. Slopes should be less than about 4:1. Soils should be suitable for growth of upland vegetation.

The above configurations are more conveniently accomplished if grading is done before water is admitted. Once an area is wet, earth moving equipment is less easily supported.

5. Outlet Structure

For those situations where the tide levels in the marsh are to be managed, an automatic slide gate controlled by a water level sensor (as has been installed at the Palo Alto Flood Basin) offers the greatest flexibility where electrical power is available. Where electrical power is not available, a gravity-controlled flap gate can be designed. Trash barriers must always be included in the design to prevent debris from obstructing the gate. Furthermore, it is necessary to provide a back-up flap tide gate in case the control gate jams. The constricting effect of the control gate itself and of the approach culvert must be considered in analyzing the tidal hydraulics on the marsh site.

6. Drainage and Circulation

A diked-off marsh rarely retains the pre-existing mature tidal drainage system. In most instances, substantial modification and sedimentation has taken place. In order to create a new tidal drainage system, there are two approaches that can be taken.

One approach is simply to allow the tidal flows to establish a new drainage system by deposition and erosion. The problem with this approach is that a great amount of time is required for sloughs and channels to develop. Furthermore, where significant consolidation has taken place in the muds, erosion rates can be minimal, as has been observed in the Muzzi Marsh restoration. These factors can result in poor circulation and can delay the establishment of marsh vegetation.

---

*The former marsh was filled with upland material, which was not entirely removed before marsh restoration. This resulted in gravelly, highly saline, barren areas where upland material remained.

A second approach is to create a new tidal drainage system. This must be designed to provide adequate circulation, velocity, and distribution of tidal inflows and outflows to and from the marsh. The hydraulic geometry of the drainage system of a mature marsh is dictated by tidal range, tidal prism, sediment characteristics, and vegetation type. Unfortunately, little research has been done on the hydraulic geometry of natural marshes in San Francisco Bay. Therefore, the design of the drainage system should be closely modeled on the natural pattern of adjacent or nearby sloughs and channels. In the natural system, there are two distinct types of channels. Channels wider than about 5 feet have shallow gradients and act equally as conduits for ebb and flood tides. For convenience, these are referred to as "sloughs." Smaller channels, tributary to these sloughs, have steeper gradients and have appreciable flow velocities only during the ebb tide (Pestrong, 1972). This network of smaller channels is of major importance in effective drainage of the marsh plain.

a. Channel Design. In general, channel cross-sections should err on the side of being too large rather than too small. If a channel is too large, sedimentation will occur over a few years until the channel adjusts to a new hydraulic geometry. The converse is not necessarily true. Typically, slough channels should be designed at least 20 feet wide with zero slope and with bottom depths at approximately the same depth as the main outflow channel. For large marsh areas, side slopes may be at the angle of repose or, alternatively, cut back to 1:10 to allow for mud flats and diverse vegetation.

Tributary channels should be at least six feet wide and, depending on the elevation of the marsh plain, excavated to three to five feet. Side slopes should be at the angle of repose. If possible, these channels should be graded toward the main sloughs. In no case should they be excavated deeper than the main slough channel, as this may cause stagnant water ponding.

b. Drainage Design. The drainage network should be designed so that no point on the marsh plain is farther than about 100 feet from a channel or slough. Drainage channels and sloughs should therefore meander in a similar pattern to the natural system to cover the largest drainage area in the shortest length. As observed in natural systems, slough junctions should be at roughly 120 degrees. Junctions of channels with sloughs should be roughly at right angles.

If possible, channels and sloughs should be laid out to create islands within the marsh plain. In addition to providing drainage and added diversity, such channels can act as barriers to prevent human and feral animal intrusion around the marsh perimeter.

c. Circulation Design. In order to ensure that water quality is maintained, there should be adequate circulation in a typical tidal cycle. In most wetlands and salt marshes, the tidal prism is a large fraction of the total water volume in the marsh. For marshes immediately adjacent to open water, if the tidal exchange is greater than 75 percent, there should be few water quality problems. On the other hand, if the marsh is at the upstream end of a long slough, some of the water leaving the marsh during the ebb may return at high tide. If pollution dispersion is a major concern, and if the slough system is complex, computer modelling techniques can be used to predict the transport of conservative (i.e., non-decaying, such as salt) pollutants and decay of non-conservative pollutants during successive tidal cycles. However, a rough estimate of the dispersion and exchange ratio can be made using Ketchum's modified tidal prism method (Dyer, 1973) which calculates the tidal excursion for the marsh tidal prism. Generally, net dilution of greater than 50 percent should provide adequate circulation.

To improve circulation and oxygen content it is generally helpful to have areas of open water exposed to wind action, and a complex slough system allowing ebb and flow in different directions around marsh islands. It is also important to ensure that any depressions on the marsh plain are drained adequately to prevent stagnant water and excessive soil salinities.

7. Sedimentation and Erosion

In its natural state, a salt marsh is in dynamic equilibrium with the sedimentation and erosion caused bv the tidal flows. San Francisco Bay sediments are mainly flocculated clays that are easily resuspended from shallow mud flats by wave action. Because the settling velocities of these clay flocs are so low, they remain in suspension for an appreciable time and are carried onto the marsh with the flood tide. At slack water some of the suspended mud settles out, assisted by the mild eddying around vegetation which causes aggregation of the clay flocs. At the ebb tide, as velocities increase, some of the clay particles are resuspended. Others, however, are protected, and over time develop electrochemical bonds with surrounding particles. This means that the erodability of the sediment decreases with time, and the velocity required to scour even weakly consolidated muds is greater than the minimum velocity required to keep the clay flocs in suspension.

The marsh plain is built up over time, both by particle accretion and by the volume of organic matter (roots, rhizomes, etc.) in the soil, to roughly high water level so that marsh build-up keeps pace with the gradually rising sea level (Atwater, 1979). Drainage channels and sloughs originally formed in the mud flats are preserved and accentuated as the marsh level is built up. Their hydraulic geometry adjusts so that sedimentation during slack water is balanced by erosion during the ebb tide.

When tidal action is restored to diked wetlands, significant sedimentation should be anticipated in areas where velocities are low and the water is deep. Sedimentation of up to one to two feet per year can occur, for example, at the landward end of a cut-off slough. Therefore, the hydraulic geometry of slough channels can change rapidly from the initial conditions. On the marsh plain, initial sedimentation rates may be several inches in the first year depending on the degree of subsidence. This sedimentation rate declines exponentially over time as the plain reaches the effective high water level.

Sedimentation can appreciably reduce the tidal prism over a five to ten year period. This reduction can affect circulation as well as the tidal range upstream of sloughs that are significantly reduced in cross-section.

a. Sedimentation and Erosion Control. The rate of sedimentation and erosion should be anticipated in the design of the marsh restoration. For Bay muds in general, deposition occurs when the bed shear stress is below about 0.6 dynes/cm2 or .0035 pound/ft. (Krone, 1979). Practically, for typical depths encountered in sloughs and channels, this is equivalent to a critical average velocity of 0.5 to 1.0 ft./sec. The newly deposited sediments will erode above this velocity, with erosion rate increasing as a strong function of velocity (older consolidated deposits take more time and velocity to erode). Below this velocity, deposition takes place, but the deposition rate is more strongly related to the time period for which the tide has low velocity than to the actual velocity itself.

Sometimes it may be necessary to design the dimensions of an outlet channel to be self-scouring. Because of the great variabilities and uncertainties in predicting mud deposition, it is difficult to project what the self-scouring velocity will be. It has been suggested (Krone, 1979) up to 4 dynes/cm2 be required. In no event should bed shear stresses less than twice the critical velocity be used.

A rough indication of maximum deposition rates can sometimes be obtained from dredging records of adjacent areas. Those usually represent maximum sedimentation conditions because dredged areas often act as traps for gravity mud flows along the channel bottom.

b. Wave Erosion Control. In locations exposed to a long fetch from a prevailing wind direction, another factor to be considered is the effect of wave action. Riprap protection may have to be provided on the seaward side of levees, as at the Johnson's Landing marsh restoration.

When inboard levees are susceptible to wave attack, marsh vegetation, such as cordgrass or alkali bulrush, can be used for protection. In this situation the marsh plain should be graded to allow an approximately 50 feet wide bench of marsh plain at an elevation to allow development of a fringe of cordgrass or bulrush.

c. Outlet Structure Maintenance. If the tidal inflows and outflows pass through a culvert or slide gate, sedimentation can occur causing obstruction. Culvert inverts should therefore be constructed at slightly higher elevations than the bottom elevations on either side. There should be easy access to clear away any sediment from the vicinity of the slide gate. Vegetation is a particularly troublesome problem in submerged conduits. Oversized conduits or provision for cleaning should be considered in outlet structure design. Design for easy maintenance and arrangements for continued inspection and care should be included in restoration plans.

Hydraulic Design of Marshes Used For Stormwater and Wastewater Treatment

The design criteria to optimize the treatment capacities of restored wetlands will partially depend on whether the input water will be treated sewage effluent or stormwater runoff. At the present time, sewage treatment effluent discharge is strictly regulated by local, state, and federal agencies. In general, treatment plant effluent is discharged directly to large bodies of water (Sacramento River, San Francisco Bay, Pacific Ocean) to promote immediate dilution. Although discharge to a marsh for further treatment is not prohibited, such a project would probably require extensive study, a long approval process, and long-term monitoring.

Treatment afforded to stormwater runoff by a marsh would be viewed as an additional benefit of a wetland, and would not be subject to the discharge permit requirements applicable to sewage effluent discharge. The Regional Water Quality Control Board (RWQCB) now allows stormwater runoff to drain directly into the Bay. However, the 1982 Water Quality Control Plan, San Francisco Bay Basin, allows the Regional Water Quality Control Board to require permits for projects that treat surface runoff.

The availability of adjacent volumes of water for flushing must be considered. A healthy salt, fresh, or brackish water marsh requires seasonally regular and adequate fresh water flushing and exchange to prevent stagnant conditions. Sewage treatment effluent would probably provide the only economically feasible source of freshwater throughout the year. Of the 65 sewage treatment plants in the Bay Area, only the Mountain View Sanitary District in Martinez currently utilizes effluent to maintain a freshwater marsh (J. Warren Nute, Inc., 1977). It is expected that in most cases, restored marshes will continue to provide treatment only to stormwater runoff. In the following sections on design criteria, distinctions will be made between the treatment of stormwater and sewage effluent.

1. Area of Wetland Required

A given wetland area is capable of providing treatment to a certain quantity of wastewater, depending on such factors as the rate of inflow of the wastewater, the pollutant types and their concentration in the water, and the type and condition of the marsh vegetation. When pollutant input exceeds this quantity, increasingly less pollutant removal occurs, and habitat degradation may result.

For freshwater marshes supplied with sewage effluent, the Mountain View Sanitation District project (J. Warren Nute, 1977) provides some basic design data. A detention time in the marsh of about five days is recommended; excessively short detention time precludes adequate treatment time, while too long detention time promotes anaerobic conditions. Optimum marsh depths range from one and a half to two feet. For these conditions, a marsh area of eight to ten acres would be required for a one MGD (million gallons per day) sewage treatment plant.

For marshes open to tidal action there are no detailed criteria currently available to predict required marsh area. Since the marsh is flushed twice daily, the typical detention time is 12 hours. While a longer detention time would allow greater treatment, the tidal action permits a more even dispersion of pollutants throughout the marsh and reduces "flow through" conditions, in which the incoming pollutants are discharged directly to main marsh drainage channels and flow directly to the Bay without contacting marsh vegetation. A detailed prediction of tidal marsh area to provide optimum stormwater treatment would include such factors as:

- stormwater quantities and timing of discharge (a function of watershed area, shape, climate, etc.);

- stormwater quality (dependent on land use, seasonal timing, etc.); and

- treatment capacity of marsh (dependent on marsh area, vegetation type, circulation characteristics, etc.).

These types of data are currently being evaluated in a number of Association of Bay Area Governments (ABAG) studies; specific design criteria will probably not be available for several years. For preliminary design purposes, it can be noted that the Palo Alto Flood Basin has a ratio of marsh area to upland watershed area of 1:30. A diked marsh adjacent to the Muzzi Marsh in Corte Madera, currently being considered for restoration to tidal action, has a marsh area to watershed area of 1:10. A 1:10 ration was also considered desirable for stormwater treatment in a freshwater marsh (EPA, 1977). None of these marshes show evidence of pollutant overloading.

2. Preliminary Treatment of Wastewater

A preliminary treatment of either sewage effluent or stormwater prior to discharge to the marsh is desirable. Preliminary treatment is normally provided by a settling basin designed to trap debris and allow larger sediment particles to settle out. In addition, if sewage effluent is being treated, the sediment basin should allow dechlorination of the effluent. The settling basin should be designed to remove all particles greater than a specific size. For stormwater runoff, the average annual maximum storm (two year storm) can be used for design, with the settling basin sized to remove all particles greater than about ten microns in diameter. For a two feet deep basin, this would require a detention time of one hour. The Association of Bay Area Governments recommends 2.8 hours to 2-foot depth to settle out ten micron size particles in a flow of 5,000 sq./ft/cfs. Particles +20 microns in size require 1,250 sq./ft/cfs. plus detnetion time of 0.7 hours.

Discharge from the settling basin should be controlled by a weir; the location of the weir should promote dispersion of the discharged water over a maximum area of marsh. This weir should be designed such that the settling basin can be completely drained to prevent stagnant water during the dry summer period and to allow periodic cleaning. Since the settling basin will trap a high proportion of entering sediments and pollutants, it should be designed to facilitate periodic clean out. A weir is preferred over a tide gate because ponding volume must be controlled at all times, whereas a tide gate works only as a function of tide level.

In addition to a settling basin, it may be desirable to install an oil and grease trap, since stormwater runoff often contains petrochemical residues.

3. Stormwater/Sewage Effluent Discharge Points

In general, it is desirable to maximize the dispersion of the polluted water throughout the marsh. This dispersion is controlled by the location of discharge points to the marsh in conjunction with internal circulation patterns. In particular, direct "flow through" conditions, as described earlier, are to be avoided.

An exception to this would be the situation in which the water is severely polluted, the marsh too small to treat the quantity of water, or there is a desire to maintain pristine conditions within the marsh. In this case, a direct discharge channel through the marsh would be necessary. (This is the situation in the Palo Alto Flood Basin, where sewage plant effluent is discharged directly to the Bay in a channel which crosses the marsh.)

Hydraulic Design of Marshes for Flood Protection

In several instances diked historic baylands adjacent to developed areas function as a stormwater retention basin during the winter. Such a use can be compatible with marsh restoration and enhancement, provided it is integrated with other design factors in the marsh management plan.

A diked wetland can provide flood protection to surrounding low lying areas by acting as a storage basin for stormwater runoff during high tide. Because the water surface elevation in the basin is several feet lower than the tide level, stormdrains can discharge freely from the surrounding area until the basin fills. Water is discharged from the basin to the Bay either by pumps or through tide gates that open when the tide recedes.

Freshwater marsh can be created by the storage of stormwater runoff during the winter months. This function of diked historic baylands is also compatible with salt marsh restoration because intense prolonged rainstorms that result in large volumes of runoff occur only in the winter months (from November to March) when the salt marsh vegetation is dormant. Therefore, tidal action can be introduced into the marsh from April to October and then shut off during the flood season. Furthermore, freshwater inflow into the marsh can be beneficial in creating a range of brackish water conditions at the salt marsh edge.

In some cases, as in the Palo Alto Flood Basin, the maximum tidal elevation must be restricted because of subsidence of the marsh plain. The tidal inflows and outflows, therefore, have to be closely controlled.

1. Flood Routing Calculations

If a diked historic bayland is to be used as a flood basin, a flood routing calculation should be made based on the 100-year, six-hour rainstorm falling on the surrounding watershed. To do this requires the delineation of an elevation/capacity curve for the basin based on an accurate topographic survey. Computations of inflow, outflow, and storage should be made for peak flows coincident with a high tide of a typical tidal cycle. The maximum water elevation reached in this flood routing is the design criterion to be used in determining the type and size of the outlet structure required for the enhanced restored marsh.

2. Outlet Structures

The type of outlet structure most suitable for flood basin marsh enhancement is a combination of a slide and flap gates. The slide gate can be opened during the summer either manually, as in the Mill Valley Middle School

Marsh, or automatically if there is a limitation on the tidal range, as in the Palo Alto Flood Basin. During the winter runoff the flap gates discharge whenever tide elevations are lower than the water surface in the basin. If the storage capacity in the basin is limited, pumps may be required to supplement the discharge capacity.

An adequate maintenance program is essential to ensure proper functioning of tide gates.

3. Sedimentation

Siltation in the basin may ultimately significantly reduce the storage volume. In addition, the discharge capacity of outlet sloughs may be impaired. Flood routing calculations should be made to reflect these conditions and to ensure that 100-year flood levels are not exceeded in surrounding areas.

Vegetation Establishment

The purpose of this section is to provide specific information about how a site should be prepared so that the desired vegetation and hence the preferred habitat can become established. This section will first address some general environmental conditions that must be present before marsh vegetation can be successfully established. Next, specific requirements for selected plant species will be described, so that appropriate plantings at a given site can be determined.

The purpose of marsh restoration is to re-establish viable, permanent populations of animals and plants in areas that were hydraulically disconnected from San Francisco Bay. Restoration and enhancement projects can be planned to achieve either of two objectives: to take maximum advantage of historic and existing conditions to re-establish a specific plant community; or to essentially create an environment with a particular wildlife habitat in mind.

Several variables contribute to the creation of a natural marsh: water regime, elevation, substrate, climate, water salinity, soil salinity, nutrient availability, acidity, age of substrate, and seasonal variations. These same variables, with the additional consideration of species already present, must be considered in any restoration proposal. Scientific vegetation establishment studies began on the West Coast in San Francisco Bay in 1969 by Drs. H. T. Harvey and J. P. Heath (Garbish, 1977).

1. Climate

Most climatic conditions can be disregarded in this discussion because of the relatively uniform climate around San Francisco Bay. Windspeeds, however, do vary appreciably and affect marsh establishment because of wave activity or surge. Areas with high wind and wave activity require species that can withstand high wave energies.

2. Substrate--Physical Characteristics

Loose loam to clay soils are best for marsh plant growth. Adequate leaching of soils and deposition of sediment may be necessary before vegetation can be established. Soil samples should be collected and analyzed upon completion of any required earthwork, and again after one year, to determine the suitability of the substrate for planting. Soil samples taken at the end of the dry season would probably yield the most useful information. Ideally, soil conditions during each season should be monitored. Chemical conditions described below should be met. Sediments and substrate must be carefully analyzed prior to planting.

Peat soils have poor nutrient absorption and water exchange and are highly acidic, while silty and clay soils can dry out and crack and need to be exposed to water for several weeks before planting.

Pure sand with clear water cannot support plant growth because of insufficient nutrients. Sandy soils can support plant growth but only after clay particles carried by Bay waters have settled out and mixed with the sand. Clay is essential to create an ion exchange surface from which nutrients can be yielded to the plants. It is the essential minerals supplied by either "dirty" sand or water that feed the plants. Gravel or rock substrates are not conducive to plant growth because of their mobility (shifting pebbles) or lack of rooting zone. Rock outcrops are generally unsuitable for planting because they are located in areas where waves would erode marsh vegetation and soils.

3. Substrate--Chemical Conditions

The main abiotic chemical factors determining the type of vegetation on physically suitable substrates are salinity and acidity (pH). Range of pH is thought to be fairly broad for halophytes; most can grow in soils which range from pH 4 to 9. Most nutrients, however, are more readily taken up by plants when the pH is between 6 and 8.

In most cases, salinity will be the overriding chemical factor determining marsh plant species success. Soil salinity can be drastically altered by the addition of dirt fill, so this source needs to be controlled. The length of time that vegetation is exposed to saline water can be manipulated to some extent by engineering substrate elevations relative to water level. In general, the salinity of the soil moisture on a site will be determined by the waters that feed into and drain out of the site. Water originating from sloughs fed by rainwater will be relatively low in salinity during the winter/spring rainy season, whereas high salinity waters will be supplied in summer and late fall. Restored tidal areas nearest the Golden Gate will be subject to essentially salt water. Those in the San Jose vicinity could have nearly fresh water flows because of the large discharge of nearly fresh water from the sewage treatment plant, and fresh water from Coyote Creek.

The chemistry "seen" by a plant results from a combination of the source of inflowing water and the chemical and physical properties of the soil itself. Little information is currently available comparing the organic and mineral content of disturbed marsh soils to adjacent natural marshes. Some research is now underway regarding marsh soil chemistry and, when available, new information can be applied to restoration and enhancement plans.

4. Topography

Elevation requirements of marsh vegetation must be considered (Garbish, 1977). Marsh vegetation occurs in natural marshes around the Bay between two and 11 feet above mean lower low water (MLLW).* This range of elevations has been determined by field observation of study sites around San Francisco Bay (Atwater and Hedel, 1976; Harvey, 1975; Harvey et al., 1978; U. S. Department of Commerce NOAA and NOS, 1980). Intertidal areas in San Francisco Bay have four major zones; mud flats, which range in elevation between MLLW and two to three feet above MLLW; a zone of cordgrass which grows between two and five and a half feet above MLLW; an area between four and 11 feet above MLLW containing perennial pickleweed, jaumea, alkali heath, and annual pickleweed species; and an upland area supporting peripheral halophytes such as salt grass, gum plant, and coyote brush (Harvey et al., 1977).** Upland vegetation

---

* A variety of elevation standards are used by people involved in wetlands restoration. The following definitions are some of the more common encountered in the marsh business:

Datum is a base elevation used as a reference from which to reckon heights and depths. It is called a tidal datum when defined by a certain plane of the tide.

Mean Sea Level (MSL) is a tidal datum: the arithmetic mean of hourly water elevations observed over a specific 19-year cycle.

The National Geodetic Vertical Datum 1929 (NGVD), formerly known as the Sea Level Datum of 1929, is a reference adopted as a standard geodetic datum for heights. The geodetic datum is fixed and does not take into account the changing standard of sea level.

Points on land can be referenced to a mean sea level, in which case the datum assumes zero elevation. To avoid confusion, when referring to restoration projects, heights should be identified on NGVD. Usually points are referenced to a local Mean Lower Low Water (MLLW) based on the National Geodetic Verticial Datum.

** See Table I for scientific names of species discussed in this section.

Table I

Common Marsh Plant Species Found
in
San Francisco Bay Marshes
(Harvey et al., 1977)

Common Name	Scientific Name
Alkali bulrush	Scirpus robustus
Alkali heath	Frankenia grandifolia
California bulrush	Scirpus californicus
Common tule	Scripus acutus
Coyote brush	Baccharis sp.
Gum plant	Grindelia humilis
Jaumea	Jaumea carnosa
Pacific cordgrass	Spartina foliosa
Pickleweed (annual)	Salicornia biglovii, S. europea
Pickleweed (perennial)	Salicornia pacifica = virginica
Salt bush	Atriplex sp.
Salt grass	Distichlis spicata
Endangered	
Bird's beak	Cordylanthus mollis var. mollis

grows at elevations ranging from about three feet above MHW upward. These ranges are given in relation to MLLW and MHW. When preparing marsh restoration plans for different parts of the Bay, it is important to remember that all tidal elevations contained in tide tables are based on predictions, and that these predictions for San Francisco Bay are made for tides at the Golden Gate Bridge. Predictions for other tide stations around the Bay are extrapolated from those at the Golden Gate. Since differences in tidal elevations among tidal stations vary as much as three feet for MLLW, accurate information must be determined for each site proposed for restoration.

Tidal planes for San Francisco Bay are shown in Figure A. Note that at Alviso, the mean range (MHW to MLW) is 7.2 feet, but at Chipps Island it is only 3.5 feet.

Three graphic representations of marsh vegetation profiles are presented to illustrate the plants that would probably grow at specific elevations at sites around the Bay. The three sites selected for illustration are Palo Alto (Figure B), Point San Pablo (Figure C), and Chipps Island (Figure D). These represent examples of the South Bay, San Pablo Bay, and Suisun Bay, respectively. In looking at these illustrations, it is important to know that actual Bay marshes do not exhibit steep slopes as illustrated but consist of gradually sloping or flat plains.

Tidal range is a major factor in plant distribution and is therefore useful in restoration planning (Garbish, 1977). Tidal data should be presented on all grading drawings and transferred into elevations in relation to NGVD.

5. Species Requirements

About 200 species of plants are found in San Francisco Bay marshes (Harvey et al., 1977). This report will discuss cordgrass, pickleweed, alkali bulrush, California bulrush, common tule, salt grass, salt bush, and gum plant, with brief additional comments on endangered and exotic plants. Particular needs of the major species are summarized in Table II. Table III is a summary of vegetation suggested for desired habitat functions.

a. Pacific cordgrass is found at the lowest marsh elevations throughout San Francisco and San Pablo Bays. In the brackish waters of Suisun Bay it is replaced at the lower elevations by California bulrush and common tule. Cordgrass can tolerate considerable tidal submergance (up to 21 hours/day) because it has a well-developed system of air passages which transport oxygen to the roots. Favored tidal elevations are 3 feet above MLLW to MHW. Seeds of this species germinate, and seedlings grow best, in nearly fresh water, although salinities up to 35 parts per thousand (ppt) can be tolerated (Cain and Harvey, 1981). Cordgrass cannot tolerate high salinites during seed germination or during growth periods.

Several cordgrass planting techniques have been tried in San Francisco Bay (Mason, 1973; Harvey, 1975; Newcombe and Pride, 1975; Floyd and Newcombe, 1976; Morris et al., 1978; Newcombe et al., 1979). The preferred technique should depend on the conditions at the site. In the absence of wave action, sprigs or seedlings may be used. To obtain seedlings, it is best to harvest seeds from the parent plant as soon as they are ripe. Store the seeds in salt water at about 40°F. Allow an after-ripening maturation of seeds in

Figure A

Figure B, C, and D

TABLE III

VEGETATION AND HABITAT FUNCTION
(Prepared by H. T. Harvey and J. R. Cherniss)

Desired Ultimate Habitat Function	Vegetation to be Planted First
Lower edge stablization	Cordgrass, California bulrush
Levee or bank stablization	Cordgrass (bioconstructs) California bulrush
Freshwater marsh habitat	Alkali bulrush, tule, California bulrush
Upland/Transition resources and freshwater pond	Natural perennial and annual vegetation
Waterfowl feeding	Alkali bulrush, brass buttons
Coot discouragement (during young propagule establishment)	Wire netting (temporary--remove when vegetation established)
Shrew cover	Pickleweed, bulrushes
Salt marsh harvest mouse habitat	Pickleweed, periperhal cover (gum plant, salt bush)
Least tern nesting	No vegetation
Rail habitat	Cordgrass, pickleweed
San Francisco garter snake habitat	Freshwater marsh vegetation
Endangered plants	Site specific determination required for species and conditions
Mosquito abatement	Prevent stagnant pools
Brackish marsh	Alkali bulrush, California bulrush
Wastewater treatment (Water quality control, pollutant removal)	All marsh species appropriate to site, especially pickleweed and alkali bulrush

storage for two months. Before germinating, add a few inches of water to the storage container; seeds which rise to the top are infertile and should be removed. Germinate seeds in a nursery and plant seedlings between March and May (Mason, 1973). Successful use of seeds or seedlings requires quiet water where neither algal mats or predation (e.g., from coots) occurs.

Where strong wave action is prevalent, bioconstructs (composed of cordgrass plugs* with embedded mussels) are more effective than simple seedling plantings (Newcombe et al., 1979). The bioconstructs should be placed side by side and pegged into place in order to keep them from washing away. In areas where moderate or intermediate water movement occurs, the highest survival rate with the least cost and effort is obtained by planting cordgrass plugs made of four to six inch clumps of mature cordgrass. These clumps should be placed one half or one meter from each other (Morris et al., 1978). Optimal planting time for cordgrass propagules is February to April.

b. Pickleweed is found in nearly all types of marshes around San Francisco Bay. It is the most salt tolerant plant of those occurring in Bay marshes, and thus can minimize competition pressures by living in physical conditions intolerable to most other plants. Pickleweed is the preferred vegetation type for the endangered salt marsh harvest mouse.

Pickleweed is a fecund seed producer. All experiments testing pickleweed's ability to colonize new substrates (that have been subject to an adequate water regime as described in the preceding Hydraulics section) indicate that pickleweed can become established with little or no management intervention. The main requirements are that parent plants be located near the desired area of propagation--or patches of pre-existing stands are left on the site--and that soil salinities be between 15 and 50 ppt (Harvey, 1970; Newcombe and Pride, 1975; Floyd and Newcombe, 1976; Mall, 1969). This can be achieved by engineering potential marsh surfaces to be between MHW and about three feet above MHW. Pickleweed's inability to tolerate excessive immersion during high water eliminates it from the lower tidal elevations which are acceptable to cordgrass and bulrushes.

c. Alkali bulrush is noted for its food value to wildfowl. The seeds are the prime food for ducks in the Bay area. Restoration of marshes with this as a dominate plant would enhance wildlife use. It presently occurs throughout the brackish to freshwater fringes of the Bay; almost any place where a brackish situation is found, including river, stream, and water treatment plant effluent inflows.

This species survives best in brackish waters with salinity less than 20 ppt. It optimally produces seeds when soil salinities are below 15 ppt. Alkali bulrush can tolerate submergence almost to the degree cordgrass can, provided soil salinity is low. It will survive at tidal elevations four feet above MLLW to MHHW.

*plug=several shoots, nodes, and roots often with attendent soil mass.

It is relatively easy to propagate by seed, available as "red seed" from companies that harvest rice. As with other marsh plants, alkali bulrush can be transplanted from existing stock. This is a faster and more reliable method of establishment than seeding, but more costly. Advisable planting time is early spring (March through May) (George, 1963; Connelly, n.d.).

d. California bulrush and common tule are found at the lower elevations of brackish marshes (salinity less than 20 ppt). These plants are useful in erosion control against all but the higher velocity wind and wave forces. They are known to tolerate a wide range of soil types. These species are tolerant of inundation for long periods and require year round moisture or inundation. Their distribution around the Bay is similar to alkali bulrush, though not as extensive.

Few propagation studies have been conducted for California bulrush or common tule. As with most inundation tolerant hydrophytes, they reproduce by the vegetative means of rhizome production. Natural establishment occurs readily, but certain sites may require planting with plugs consisting of root, shoot, and rhizome masses. This planting should take place in late winter or early spring at tidal elevations between two feet above MLLW and one foot above MHW (Mall, 1969).

e. Gum Plant often occurs at the upper periphery of the marsh. As a periperphal halophyte, it serves as cover for salt marsh harvest mice during highest tides. Without such cover, mouse populations are jeoparidized by predation from herons, gulls, and raptors.

This perennial shrub flowers throughout most of the year so seeds are available almost anytime. Like most salt marsh plants, its seeds have a higher germination success rate in the lower salinity waters. Gum plant is therefore best propagated in late winter to early spring, when rain runoff dilutes water salinity. It does not tolerate prolonged immersion. Seeds should be scattered in the selected area on multiple occasions during the appropriate time period to increase chances of successful establishment at favorable elevations (Harvey, 1970).

f. Salt grass like gum plant, grows in the upper periphery of the marsh (within San Francisco Bay). This plant cannot tolerate much tidal immersion. A salinity of 30 ppt is optimal for salt grass, and it is tolerant of moderate wave forces.

Mature salt grass can be transplanted whole or seedlings can be planted. Transplants should take place in the winter-spring months. Seeds can be harvested from established stands in the fall, stored dry at room temperature, then germinated and the seedlings planted in spring (Newcombe and Pride, 1975).

6. Endangered Species

Endangered species deserve special attention when marsh restoration projects are undertaken. If specific restoration sites fall within the known range of endangered plant species, efforts should be made to propagate and encourage these. Little is known of the best method for doing this with endemic marsh species; however, the transplanting of whole young plants from relatively dense stands of existing populations should be tried, as well as the collection and sowing of seed.

7. Exotic Plants

Exotic plants (introduced, foreign, non-native) should not be used in restoration efforts. This is because exotic species are likely to outcompete and replace natives and usually do not provide comparable resource value to native wildlife. An example of this is the invasion of the pickleweed zone by non-native Spartina spartinae intentionally planted at Creekside Park, Marin County. The foreign grass has moved to the marsh shoreline along Corte Madera Creek. This infestation may threaten local survival of the endangered salt marsh harvest mouse (Harvey and Stanley Associates, 1982).

8. Upland and Transition Zone Enhancement

Areas of upland vegetation and transition zones (between marshlands and associated uplands) should be established around restored or enhanced marshlands (Harvey et al., 1978). Areas adjacent to freshwater wetlands should be planted with perennial herbs and forbs to encourage nesting by puddle ducks and other water birds. Native upland cover species should be planted to provide nesting and refuge spots and food sources.

Planting should be initially experimental, as soils of initial high salinity will support different species once they have been leached. Coyote brush and other brushy species should be controlled if the area is to be managed for nesting waterfowl.

Near restored tidal marsh, upland species can be planted above the level of tidal action. Native plants of the Bay Area which survive above tide level in soil that was originally salt marsh soil, and has been removed from tidal influence and leached by rains, include coyote brush (Baccharis pilularis consanguinea), toyon (Heteromeles arbutifolia), and coast live oak (Quercus agrifolia). Other natives which should be encouraged in transition zones because they produce good cover for small mammals are alkali heath, salt grass, and gum plant.

Follow-Up Management

Without a long-term management plan, restoration efforts will probably fail. Monitoring programs for water and soil parameters, plant growth and health, and substrate stabilization need to be built into the restoration process. Modifications in water regime may be needed later. Control of amount and timing of water inflow and outflow from a restored area is important for successful marsh plant establishment, mosquito abatement and wildlife use.

1. Vegetation Management

If currents are slow, erosion minimal, and a parent source is available, vegetation will often naturally occur and planting will not be necessary. In some such cases, however, uncontrolled spread of some types of species can limit diversity and/or inhibit good water circulation. Vegetation diversity can be improved by establishing dry and partially submerged islands, and occasionally draining sections to maintain dispersed tule stands. It would be more costly and indiscriminately damaging to periodically remove vegetation through mechnical and manual means or with herbicides.

Filamentous algae often become overly abundant in freshwater systems. Maintaining adequate circulation and limiting nutrient input should control algae.

Invasion of non-native vegetation should be curtailed as early as possible; the sooner this is accomplished, the less drastic action required.

2. Hydrological and Structural Maintenance

The physical characteristics of an enhanced or an artifically created marsh need to be monitored. Flow structures need to be checked to insure proper inflow and ouflow of water. Water samples should be collected periodically so that water quality problems can be avoided or quickly corrected. Levees should be inspected regularly so that damage caused by burrowing animals, erosion, or subsidence can be corrected. Periodic draining of the marsh may be required to facilitate management.

3. Animal Management

A well-managed marsh requires periodic monitoring of less conspicuous aquatic and benthic organisms, such as soil microbes, invertebrates, phyto- and zooplankton (including fish larvae), and fish themselves. Diversity can be encouraged by creating or introducing some artificial substrates, although this entails additional costs. Generally, diverse revegetation and substrate, combined with good water circulation, will, if lasting, induce a diverse faunal community. However, in certain cases it may be desirable to introduce particular species into the system. Much is still unknown about survival and balanced proliferation of invertebrate and most vertebrate species in artificially induced marsh habitats. Within the time frame of observations made in Bay Area restoration and enhancement projects, animal productivity has never equalled that of natural marshes. Follow-up management should consider the extent to which stable, diverse, native animal populations have become established.

Vector and Disease Control

Marsh restoration projects should be designed to not create conditions that cause disease or pest problems. Proper management of the marsh can limit this possibility.

Adult and larval mosquitoes, like other small insects, are an integral part of the food chain, providing an important food source for insectivorous birds, amphibians, and fish. Some species, however, transmit diseases; others are considered pests, particularly in urbanized areas. Restoration plans should be designed to avoid creating conditions that encourage mosquito proliferation.

Mosquito-breeding conditions occur when areas of standing water are present during the spring and summer. To prevent ponding, a potential restoration site should be graded to achieve proper drainage. If grading is infeasible or ponded areas develop, ditching may be necessary. Recirculation ditches that are approximately one and a half feet wide and one and a half feet deep are generally adequate to connect ponds to drainage channels. Large expanses of open water, subject to wind and wave action, will discourage mosquito production. Small fish, particularly mosquito fish, and other aquatic organisms can be effective predators on mosquito larvae, but generally do not penetrate dense stands of vegetation. In all cases, early consultation with mosquito abatement districts should occur to avoid creating pest or vector mosquito problems.

The most serious disease affecting waterfowl is botulism. The factors that create conditions which are condusive to botulism are not precisely known, although the bacterium Clostridium botulinum is ubiquitous in soils and is important to nitrogen cycling. It is only the proliferation of the bacteria, with toxic side effects, which leads to outbreaks of botulism in waterfowl. Briefly, management techniques for avoiding outbreaks include manipulating water depth to minimum but fluctuating levels, maintaining water flow through cells and drainage channels, removal of debris and dead vegetation, and maintaining fairly steep configuration of banks.

Conclusion

Until recently the complexities of the conditions and forces that create a marsh were not well understood. As a result many restoration and enhancement projects were not entirely successful. For example, at the Faber Tract in Palo Alto there was not adequate water circulation within the wetland because the pipes installed between the Bay and the marsh were too small. At the Corps' project at Alameda Creek the site was made too high by the placement of dredge spoils so the preferred marsh plant, cordgrass, could not grow. At the Creekside Park in Marin County non-native plants were used; they are now crowding out native marsh plants. At the Muzzi Marsh in Corte Madera, contractors could not construct channels for water circulation because the soils would not support earth moving equipment. These experiences demonstrate the importance of gathering all the necessary data, doing thorough planning, and preparing complete drawings and specifications.

Designing a successful marsh restoration or enhancement is difficult. The soil conditions and elevations within in the site must be analyzed carefully. Any modifications must take into account tidal fluctuations at the selected site, sedimentation, and plant requirements. The hydraulic, botanical and topographic aspects require expert analysis. Clear and complete plans for restoration projects must be prepared to assure satisfactory implementation. Changes will occur over time and the effects of such changes must be understood. Projects should be monitored to assure that the desired conditions occur and to provide new information for future projects.

Appendix A consists of a checklist to help agencies and developers better understand the information and work that will be necessary to design a marsh restoration or enhancement project. Appendix B is a condition that BCDC and other regulatory agencies should use whenever restoration and enhancement projects are required.

APPENDIX A

RESTORATION AND ENHANCEMENT CHECKLIST

The following checklist identifies the information necessary to plan marsh restoration or enhancement:

1. Based on a survey, prepare a topographic map of the selected site in one foot contours. All elevations should be relative to National Geodetic Vertical Datum (NGVD). Include a vicinity map showing storm drains, the elevation of adjacent surrounding properties, and the limit of 100-year tide.

2. Prepare a topographic map in one foot contours showing proposed modifications to the site. Include typical cross-sections showing proposed elevation of the marsh plain, any channels and any high areas. Include figures for the estimated tidal range related to Mean Higher High Water, Mean High Water, Mean Lower Low Water, Mean Sea Level, the maximum predicted tide, and the 100-year tide. Show figures for the ratios of typical horizontal to vertical slopes for existing and proposed levees and channels or sloughs. Show proposed plant species along the cross-sections of their expected zone of growth.

3. Prepare calculations for determining the size of any levee breaches or pipe installations. Show the amount of cut and fill, the amount of material to be placed to strengthen the levee, and the expected tidal exchange. The expected tidal range should show expectations both inside and outside the levee breach. If plants will be used to moderate tidal forces at the breach, indicate the plant species that will be used. If plants will not serve that function, specify what rip-rap or other engineering solution will assure the integrity of the levee breach. Prepare a detailed drawing of any inlet-outlet structure to be placed, with a schedule of operation.

4. Gather soil information identifying the type of soils found at the site and the type to be used if fill will be placed. Include quantitative measurements of salinity, pH, organic content, and bulk density. In addition to the soil analysis, the following water quality parameters should be analyzed: salinity, pH, biochemical oxygen demand (BOD), dissolved oxygen (DO), and, if appropriate, heavy metals.

5. Prepare a schedule indicating when fill, dredging or grading will occur, the time to be allowed for settlement, the time when levee breaches or inlet structures will be operable and the time when planting will occur. Include an estimate of the extent of expected sedimentation over a ten-year period.

6. Prepare a monitoring program to measure water quality, soil characterisitics, plant survival and growth rates, and expected

wildlife use. The program should last five years. The monitoring program should describe how modifications will occur if adverse conditions are identified.

7. Provide evidence that the project meets Mosquito Abatement Distict mosquito control criteria.

APPENDIX B

CONDITION

The following condition is a model to be used when large marsh enhancement or restoration projects are required. Modifications to the condition may be necessary to accommodate particular sites or projects.

1. Restoration Plan. Prior to the commencement of any work at any location pursuant to this authorization, the applicant shall submit a plan and program, to be approved by or on behalf of the Commission for the restoration and enhancement of a parcel consisting of not less than ____ acres located at _______________. The plan and program shall contain the following:

a. Site Conditions and Modifications. A topographic map of the site in one-foot contours and a topographic map showing the proposed modifications. All elevations shall be relative to National Geodetic Vertical Datum (NGVD). Include typical cross-sections showing proposed elevation of marsh plain, any channels, and any high spots. Show figures for the ratios of typical horizontal to vertical slopes for existing and proposed levees, channels, and sloughs. Show proposed plant species along the cross-sections according to their expected zone of growth. Include a vicinity map showing storm drains, the elevation of adjacent surrounding properties, and the limit of the 100-year flood. Include figures for the estimated tidal range related to Mean Higher High Water, Mean High Water, Mean Lower Low Water, Mean Sea Level, the maximum predicted tide, and the 100-year tide.

b. Levee breaches. For any levee breaches show calculations for determining the size of any levee breach or pipe to be installed. Indicate the amount of cut and fill, the amount of material to be placed to strengthen the levee, and the expected tidal exchange. The expected tidal range should show expectations both inside and outside the levee breach. If plants will be used to protect the levee from erosion or undercutting, specify the type of plants. If plants will not be used, describe how the breach will be protected from erosion and undercutting. Prepare a detailed drawing of any inlet-outlet structure to be placed, with a schedule of operation.

c. Soil and Water Information. Submit a report identifying the type of soils found at the site and the type of any fill to be placed at the site. Include quantitative soil measurements of salinity, pH, organic content, and bulk density. Include water analysis of salinity, pH, biochemical oxygen demand (BOD), dissolved oxygen (DO), and, if appropriate, heavy metals.

d. Schedule. Include a schedule indicating when fill, dredging or grading will occur, the time to be allowed for settlement, the time when levee breaches or inlet structures will begin to function and the time when planting will occur. Include an estimate of the extent of expected sedimentation over a ten-year period.

e. Monitoring. The applicant shall be responsible for monitoring the site for five years after the restoration project has been completed. Such monitoring shall include measuring the water quality, soil characterisitics, plant survival and plant growth rates. Should adverse conditions be identified, the applicant shall take corrective action as specified by staff.

BIBLIOGRAPHY

Anderson, W., 1970. A preliminary study of the relationship of salt ponds and wildlife: South San Francisco Bay. California Department of Fish and Game 56 (4): 240-252.

Army Corps of Engineers, 1980. Bank erosion control with Pacific cordgrass on the southern Pacific Coast (Humboldt Bay to Mexico). Coastal Engineering Technical Note TN-V-4.

Association of Bay Area Governments (ABAG), 1979. Treatment of stormwater runoff by a marsh/flood basin. ABAG, Berkeley, CA.

Atwater, B. F., S. G. Conrad, J. N. Dowden, C. W. Hedel, R. L. MacDonald, and W. Savage, 1979. History, landforms, and vegetation of the estuary's tidal marshes. In T.J. Conomos (ed.), San Francisco Bay: The Urbanized Estuary. Pacific Division, American Association for The Advancement of Science, San Francisco, California.

Atwater, B. F. and C. W. Hedel, 1976. Distribution of seed plants with respect to tide levels and water salinity in the natural tidal marshes of the northern San Francisco Bay estuary, California. U. S. Geological Survey.

Balling, S. S., T. Stoehr and V. H. Resh, 1980. The effects of mosquito control recirculation ditches on the fish community of a San Francisco Bay salt marsh. California Fish and Game 66 (1): 25-34.

Brittsan, Don, 1980. Farm Advisor, Marin County. Personal communication.

Burns, A., 1972. Report to the Board of Marin Audubon Society on a marsh in Tiburon, California

Cain, D. J. and H. T. Harvey, 1981. Evidence of salinity-induced ecophenic variation of cordgrass, Spartina foliosa. Trin. Manuscript in print, Madrona.

California Department of Fish and Game, 1978. At the Crossroads: a report on California's endangered and rare fish and wildlife.

California Native Plant Society, 1980. Inventory of rare and endangered vascular plants of California. Spec. Publ. No. 1.

Cameron, G. N., 1972. Analysis of insect trophic diversity in two salt marsh communities. Ecology 53 (1): 58-73.

Carpelan, L. H., 1957. Hydrobiology of the Alviso Salt Ponds. Ecology 38 (3): 375-390.

Chow, V.T., 1959. Open Channel Hydraulics. Section 17-6. McGraw, Hill Ltd. New York.

Clark, J., D.D. Loh, and J. D. Caudill, 1980. California coastal catalog: an ecological guide to the planning and conservation of the California coast. American Littoral Society Spec. Publ. 10.

Connelly, D. P., n. d. Propagation of selected native marsh plants in the San Joaquin Valley. California Department of Fish and Game, Wildlife Management Leaflet 15.

Day, J. W., W. G. Smith, P. R. Wagner, and W. C. Stone, 1973. Community structure and carbon budget of a salt marsh and shallow bay estuarine system in Louisiana. Centers for Wetlands Resources, Louisiana State Univ. Publ. LSU-SG-72-04.

Demgen, Francesca, Demgen Aquatic Biology. Personal communication.

Dyer, K. R., 1973. Estuaries, a Physical Introduction. John Wiley Publishing Co., New York.

Environmental Protection Agency (EPA), 1977. Urban runoff treatment methods, Volume 1, non-structural wetland treatment. EPA-600/2-77-217.

Fischer, H. B., 1972. Pollutant dispersion in Bolinas Lagoon, Marin County, California. U. S. Geological Survey Professional Paper No. 582-B.

Floyd, K. W. and C. L. Newcombe, 1976. Growth of intertidal marsh plants on dredge material substrate. U. S. Army Corps of Engineers, San Francisco Bay Marine Research Center Rept.

Garbish, E. W., 1977. Recent and planned marsh establishment work throughout the contiguous United States: a survey and guidelines. U. S. Army Corps of Engineers.

George, H. A., 1963. Planting alkali bulrush for waterfowl food. California Department of Fish and Game. Management Leaflet 9.

Gilbert, G. K., 1917. Hydraulic mining debris in the Sierra Nevada. U. S. Geological Survey, Professional Paper 105.

Gill, R., 1972. South San Francisco Bay breeding bird survey, 1971. Wildlife Management Branch Administrative Report No. 72-6.

Haines, E. B., 1977. The origins of detritus in Georgia salt marsh estuaries. Oikos 29: 254-259.

Harvey H. T., 1966. Some ecological aspects of San Francisco Bay. Unpublished memorandum to the San Francisco Bay Conservation and Development Commission.

_______________, 1970. Grant Avenue Overpass marsh planting. Unpublished memorandum to the San Francisco Bay Conservation and Development Commission.

Morris, J. H., C. L. Newcombe, R. T. Huffman, and J. S. Wilson, 1978. Habitat development field investigations, salt pond #3, marsh development site, South San Francisco Bay, California. U. S. Army Corps of Engineers W.E.S. Technical Rept. D-78-57.

Newcombe, C. L., J. H. Morris, P. L. Knutson, and C. Gorbics, 1979. Bank erosion control with vegetation, San Francisco Bay, California. U. S. Army Corps of Engineers, Coastal Engineering Research Center. Misc. Rept. 79-2.

Newcombe, C. L. and C. R. Pride, 1975. The establishment of intertidal marsh plants on dredge material substrate. U. S. Army Corps of Engineers through San Francisco Bay Marine Research Center, Inc.

Nichols, D. R. and N. A. Wright. 1971. Preliminary map of historic margins of marshland, San Francisco Bay, California. U. S. Department of the Interior, Geological Survey Open File Report.

Nute, J. Warren, Inc., 1977. Mountain View Sanitary District marsh enhancement pilot program. Progress Report No. 2.

Pestrong, R. 1965. The development of drainage patterns on tidal marshes. Stanford Univ. Publ. Vol. X, No. 2.

Pestrong, R. 1972. Tidal flat sedimentation at Cooley Landing, S. W. San Francisco Bay. Tech. Report under Office of Naval Research, No. 4430(00) with Stanford University.

Small, M. M. and C. Wurm, 1977. Data report, meadow/marsh/pond system. Brookhaven National Laboratory, Upton, New York.

Southworth, J., Naturalist, Coyote Hills Regional Park. Personal communication.

U. S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), 1980. Tide tables for west coast of North and South America. Appendix A, Table 3.

U. S. Department of Commerce, NOAA and National Ocean Survey (NOS), 1980. The relationship between the upper limits of coastal wetlands and tidal datums along the Pacific Coast. NOAA, NOS, Rockville, MD. 20852.

U. S. Fish and Wildlife Service, 1979. List of endangered and threatened wildlife and plants. Federal Register 44: 3636-3653.

Zentner, J., 1981. Draft report on Wetlands Management and Restoration. California Coastal Commission.

Zetterquist, K., 1977. The salt marsh harvest mouse (Reithrodontomys raviventris raviventris) in marginal habitats. Wasmann J. Biol. 35 (1): 68-76.

______________, 1975. Growth and elevational transplant studies of Spartina foliosa in dredge materials. In The establishment of intertidal marsh plants on dredge materials substrates. San Francisco Bay Resource Center Report.

______________, 1976. In U. S. Army Corps of Engineers dredge disposal study, San Francisco Bay and Estuary, Appendix K: Marshland development.

______________, Harvey and Stanley Associates, 1982. Personal Communication.

Harvey H. T, M. J. Kutilek, and K. M. DiVittorio, 1978. Determination of transition zone limits in coastal California wetlands. Environmental Protection Agency.

Harvey H. T., H. L. Mason, R. G. Gill, and T. W. Wooster, 1977. The marshes of San Francisco Bay: their attributes and values. Unpublished technical report prepared for the San Francisco Bay Conservation and Development Commission.

Knutson, P. L., 1977. Planting guidelines for marsh development and bank stabilization. U. S. Army Corps of Engineers Coastal Engineering Research Center. CETA 77-3.

Krone, R. B., 1979. Sedimentation in the San Francisco Bay System. In T. J. Conomos (ed.), San Francisco Bay: The Urbanized Estuary. Pacific Division, American Assoc. Advanc. Sci. San Francisco, California.

Madrone Associates, 1974. Environmental impact report for Sequoia Pacific Realco Lands Development, Tiburon, California. City of Tiburon.

Madrone Associates, R. B. Kingsley, and F. C. Boerger, 1976. Experimental marsh planting programs: Marin Country Day School and Muzzi Marsh. Golden Gate Highway and Transportation District, San Francisco, California.

Mahall, B. E. and R. B. Park, 1976. The ecotone between Spartina foliosa Trin. and Salicornia virginica L. in salt marshes of northern San Francisco Bay. II: Soil water and salinity. Journal of Ecology, 64(3): 793-809.

Mall, R. E. 1969. Soil-water-salt relationships of waterfowl food plants in the Suisun Marsh of California. California Department of Fish and Game. Wildlife Bulletin No. 1.

Mason, H. L., 1957. A flora of the Marshes of California. University of California Press, Berkeley.

______________, 1973. San Francisco Bay and estuary dredge disposal study: use of dredged material for marshland development. U. S. Army Corps of Engineers and San Francisco Bay Marine Research Center, Inc.