3.1 GEOMORPHOLOGY AND HYDROLOGY

This section addresses the hydrologic and landform (geomorphic) conditions and processes that could be affected by the project. In the San Francisco Estuary, cordgrasses and their removal primarily affect the landforms and tidal waters of the intertidal zone and the marshes and flats that are regularly exposed and flooded by the reach of tides. Therefore, this section focuses on those areas. It describes existing and post-project drainage, erosion, sedimentation (accretion), flood control channels, and topography. Secondary effects of hydrologic and geomorphic impacts on biological resources and water quality are addressed in those respective sections of this document.

3.1.1 Environmental Setting

This section describes the tidal hydrology and dominant landforms that comprise the Estuary margins, as well as the primary hydrologic/geomorphic processes.

The Estuarine Intertidal Zone and Cordgrass

Established stands of cordgrass affect the patterns of sediment deposition and erosion, and local rates of sediment deposition, in intertidal environments. Cordgrass roots and below-ground stem networks bind and stabilize sediments, providing resistance to erosion and limiting the mobility of tidal sediment. Emergent tall stems and dense leaf canopies create shelter zones of reduced current velocities and wave energy, filtering and trapping both suspended fine sediment in the water column, and sands transported on the Estuary bottom.

Development of the modern intertidal estuarine environment. The modern San Francisco Estuary formed within a system of "drowned" river valleys – large ancient stream valleys that were flooded by rising sea levels after the last episode of major glaciation. The modern Estuary was preceded by more ancient estuaries in the same location, each deposited during post-glacial rises in sea level, partly overlapping older deposits. Nearly all the sediment near the surface of modern tidal marshes and mudflats was deposited during the last several thousand years, much of it derived from sediment transported by Sacramento-San Joaquin Delta outflows. The modern Estuary formed when the rate of sea level rise slowed enough for delta sediments to accumulate in the lower (downstream) reaches of the estuary in pace with rising sea level, allowing a large intertidal area to emerge as the drowned valley filled again with muds. Sea level has continued to rise slowly for several thousand years, and is currently accelerating.

During the last several thousand years the San Francisco Estuary accumulated large amounts of fine sediment from natural sources, and an additional surge of sediment during the Gold Rush, when vast amounts of hydraulic mining debris from the Sierras were deposited in the Sacramento-San Joaquin river systems, and eventually to the Estuary. Accumulation of sediments in the Estuary was further increased by widespread construction of dikes in the Estuary's marshes, which reduced the capacity of the estuary to flush out deposited sediment, and stimulated expansion of new marshes over former tidal flats. Marsh growth in the shallowest, upper intertidal zones also added much organic matter (peaty material) to sediments in the areas between tidal channels, assisting the marsh in keeping pace with rising sea level. Below the limit of native marsh vegetation, these recent sediment deposits combined to form the extensive unvegetated tidal mudflats that persist in San Francisco and San Pablo Bays.

Estuary sediments. Most of the Estuary's intertidal sediments are fine clays and silts. Sands tend to deposit more locally, such as in deep channels with fast-moving currents, near stream mouths that discharge local sand loads in deltas, or near ancient submerged beach and dune deposits. The prevalence of bay mud (the typical mix of estuarine silt and clay in the Estuary) and wide, open tidal mudflats creates naturally high turbidity in most of the Estuary. The unvegetated intertidal bay surface is mobile, easily eroded and redeposited. When the tidal mudflats are submerged at high tide, winds blowing over wide reaches generate waves, currents, and turbulence that erode the upper few centimeters of the mudflats, and place them in suspension. Much of the eroded sediment redeposits locally, but currents can readily transport fine sediment to quieter environments where it is trapped. Marsh sediments, in contrast, are tightly bound, and are slowly eroded by higher wave energy or tidal energy.

Sediment transport between marsh and mudflat. Vegetated marshes, especially low cordgrass marshes in sheltered areas, are efficient sediment traps. Marshes release their stored sediment back to the bay when they erode, particularly when wave energy from the Bay causes retreat of the marsh edge. Much of the bay edge of tidal marshes (and artificial levees that replaced many of them) are now retreating as low cliffs (scarps) in stiff peaty muds formed by the tidal marsh, returning stored sediment to the bay's tidal flats and subtidal bottom. Although local areas still may accrete marsh and mudflat, the modern estuary as a whole is exporting sediment, and despite its large reserves of mud, it is in a condition of net sediment deficit**.** Mudflats provide the most yielding and mobile reservoirs of mud.

The limit of tidal marsh development in the historic, natural condition of San Francisco Estuary was influenced by the inherent limitation of the native Pacific cordgrass to tolerate wave erosion, to trap sediment, and especially its limited ability to grow at lower elevations in the intertidal zone – roughly confined to elevations above mean sea level, and below mean higher high water. At higher intertidal elevations, pickleweed and associated perennial vegetation forms stiff peaty marsh soils. This characteristic vegetation and soil unit is an essential component of the typically complex, extensive, irregular networks of narrow, steep tidal creeks and pans (pond-like depressions) of the San Francisco Estuary's tidal marshes (Pestrong 1965). Changes in the structure of the vegetation, or the lower limit of its spread over tidal mudflats and channels, and its capacity to trap and bind sediment, therefore has the potential to alter the basic form of San Francisco Bay tidal marshes and tidal creeks.

Infilling of small existing tidal marsh channels. In wave-sheltered sites of the tidal marsh interior, Atlantic smooth cordgrass is likely to establish over most of the middle and upper middle intertidal zone within channels. This has occurred in both small and large tidal channels (sloughs, small tidal creeks, old ditches, dredge lock access channels, and flood control channels) of the Alameda shoreline, especially near the point of initial invasion near the mouth of the Alameda Flood Control Channel. Other examples of this phenomenon are found within Ideal Marsh and Whale's Tail Marsh, Hayward.

High densities of Atlantic smooth cordgrass significantly reduce tidal current and wave velocities, and increase sedimentation and sediment trapping (Gleason *et al.* 1979, Knutson *et al.* 1990). Atlantic smooth cordgrass exceeds Pacific cordgrass significantly in its potential to trap and stabilize sediment (Newcombe *et al.* 1979) and grow at lower intertidal elevations (Josselyn *et al.* 1993). These effects on sediment accretion and stabilization in low-energy tidal creeks are likely to infill them where invasions occur, as observed in older invaded sites. This would be particularly effective at the lowest-energy heads of invaded tidal creeks. Small invaded tidal creeks would gradually merge with the marsh plain, leaving shorter, simplified, less branched tidal creek systems. Upper channel segments that persist after invasion would probably also become narrower, and possibly steeper and deeper as well. Channel morphology in uncolonized portions of remaining larger channels may compensate for reduced capacity by eroding (widening or deepening), if tidal prism (volume of tidal water exchanged per unit area) is conserved. It is also possible that marshes may simply infill and exchange proportionally more tidal prism as sheetflow, or become poorly drained, as do many cordgrass meadows in the southeastern U.S. Overall, either pattern would result in less penetration of the marsh plain by the characteristic small, irregular, branched tidal creeks typical of San Francisco estuary tidal marshes. A more homogeneous topography would be expected. This may approximately replicate the typical tidal marsh topography of Atlantic coastal plain estuaries.

Partial damming or obstruction of tidal channels and water intake structures with cordgrass litter. Luxuriant above-ground biomass production from extensive cordgrass marshes would result in proportionally large seasonal deposition of cordgrass litter (dead stems and leaves floating or cast ashore in large rafts). Massive tidal litter deposits tend to accumulate at sheltered indentations in shorelines (coves, corners), and at the upper ends of tidal sloughs. Small canals leading to water intakes for man-made lagoons, managed diked marshes, or salt ponds would be at high risk for periodic obstruction with large volumes of litter (typical of productive cordgrass marshes of the Atlantic and Gulf U.S. coastlines).

Infilling and narrowing of larger sloughs and flood control channels. Colonization of the intertidal portions of wide tidal channels by Atlantic smooth cordgrass tends to trap abundant sediment and develop wide bands of low marsh in former channel side-slopes. This has occurred along the Alameda Flood Control Channel, a re-engineered tidal slough where the presence of Atlantic smooth cordgrass appears to have accelerated infilling of the channel.

Infilling of existing tidal marsh pans. Because Atlantic smooth cordgrass is able to colonize very poorly drained flats, marshes, and pans, short-form cordgrass stands will expand over the beds of most shallow submerged salt pans. The establishment of surface roughness in the pans will promote sedimentation and stabilization of deposited sediments, raising bed elevations of invaded pans. Pans would undergo gradual transformation to poorly drained short-form cordgrass marsh, or become significantly reduced in size. Some pans with moderate tidal drainage would become pure Atlantic smooth cordgrass marsh. Turbulence and water circulation within larger pans, driven by wind-stress currents and small waves, would be significantly reduced. Standing water within the pan would be essentially stilled except when the marsh surface is submerged by extreme high tides.

Establishment of typical homogeneous Atlantic cordgrass marsh topography in restored tidal marshes. Diked baylands restored to tidal flows initially develop drainage patterns on new mudflats. Drainage patterns of mudflats develop into tidal marsh creeks, and are modified by interactions with vegetation. The early establishment of initially dense, tall-form Atlantic smooth cordgrass would abort the development of complex creek networks, and promote the development of wide marsh plains with short, wide tidal sloughs with relatively few short branch creeks. Pans would be highly unlikely to develop in restored tidal marshes dominated by Atlantic smooth cordgrass. Instead, poorly drained short-form cordgrass plains would mature over decades.

Conversion of dynamic mudflat surfaces to stabilized or accreting cordgrass marsh. Mudflats that currently act as sources of sediment for marsh accretion or sediment nourishment of other mudflats would instead become sediment sinks (sites which trap sediment derived from erosion of other mudflats) once they are colonized by Atlantic smooth cordgrass.

Interference with tidal marsh restoration in designated diked bayland sites (sediment competition). The capacity of mudflats to act as sources of sediment to nourish developing restored tidal marshes in former diked baylands would be reduced. Limited sediments would be spread over larger marsh areas than intended by tidal marsh restoration projects, increasing the competition for sediment among these areas. Interactions of this effect with sea level rise could result in widespread delayed or arrested tidal marsh development at the low marsh (cordgrass) stage.

Conversion of open, dynamic estuarine beaches to vegetated, stabilized relict beach ridges and salt marsh. Estuarine beaches depend on sufficient wave energy to reach the foreshore (the intertidal zone in front of the beach) and the beach itself to maintain the beach. If wave energy is intercepted by dense cordgrass vegetation in the foreshore, sand that is naturally exported to the beach system cannot be resupplied, starving the beach. If sand above ordinary tides is not periodically eroded and redeposited in dynamic storm and calm cycles, it soon develops dense vegetation. Atlantic smooth cordgrass in the San Francisco Estuary has produced dense marshes in what were formerly open beach foreshores, and caused beaches to be engulfed by salt marsh. Marsh-engulfed beaches become immobile, relict beach ridges. This has occurred through the 1990s at several central San Francisco Bay beaches: Crown Beach, Alameda; Roberts Landing sand spit, San Leandro; and southeastern Hunters Point, San Francisco.

3.1.2 Analysis of Potential Effects

Potential effects and mitigation measures are summarized in **Table 3.1-1** and **Table 3.1-2**, respectively.

Significance Criteria

The thresholds for "significance" of impacts to geology and hydrology from implementation of the control alternatives of the San Francisco Estuary are based in part on specific regulatory standards from relevant environmental laws or regional plans, and on interpretation of the general physical context and intensity of changes in currents, waves, circulation, deposition, and erosion within the Estuary.

Other state laws, regulations, and policies and that apply to the geologic and hydrologic conditions in the San Francisco Estuary include the McAteer-Petris Act, San Francisco Bay Conservation and Development Commission's Bay Plan (BCDC Bay Plan), and the Porter-Cologne Act. These laws, regulations, codes, and plans identify the importance of the regional patterns of sediment deposition and erosion within sloughs, tidal flats, and marshes; the conservation or expansion of tidal prism (volume of tidewater exchanged within a given area), patterns of tidal currents, and large-scale fluctuations in gradients of salinity and nutrients within the Estuary, related to tidal currents, and transport of sediment and freshwater discharges. The principal environmental laws pertinent to evaluation of the level of significance to environmental impacts in the San Francisco Estuary are the California Environmental Quality Act (CEQA), which includes significance considerations in Appendix G of its Guidelines, and the federal Clean Water Act (CWA) as implemented via the San Francisco Regional Water Quality Control Board's Basin Plan for San Francisco Bay. The Clean Water Act's section 404(b)(1) guidelines for evaluation of discharges of dredged or fill materials (one incidental aspect of numerous proposed activities considered in this EIR/S) provide specific guidance for evaluating significant impacts to special aquatic sites, including wetlands in Subpart H. These include factors that cause or contribute to "significant degradation of the Waters of the United States," with emphasis on the persistence and permanence of effects. CEQA Guidelines Appendix G Environmental Checklist includes the following applicable criteria of significance:

- Resulting in substantial soil erosion;
- Substantially alter the existing drainage pattern of the site or area…in a manner which would result in substantial erosion or siltation on-or off-site;
- Substantially alter the existing drainage pattern of the site or area or substantially increase the amount of surface runoff in a manner which would result in flooding on- or off-site.

Based on these laws ,regulations, and policies, geomorphic and hydrologic effects are considered "significant" if they cause relatively high magnitude, persistent, or permanent changes in the following factors:

- Changes in the pattern or rate of sediment erosion or accretion;
- Changes in the reach or flow of twice-daily tides in the San Francisco Estuary;
- Changes in local wave climate (prevailing wave energy);
- Changes in prevailing current volumes or velocities, and associated capacity to transport nutrients, water, salts, and sediments; and/or
- Changes in the structure, distribution, or pattern of tidal channels and flats.

Geomorphic predictions (both qualitative and quantitative models) become less accurate and precise over long periods, when assumptions about key variables become uncertain estimates. A 1- to 2-year time frame is short-term, and within the direct experience (field observation and expertise) of most practicing engineers and geomorphologists working in the Estuary. A 10-year time frame is reasonably foreseeable, based on understanding of past changes recorded in bathymetric maps, aerial photographs, and sediment transport studies. This represents the near-term for qualitative, general estimates of ecological and geomorphic conditions in the Estuary. A 50-year time frame is a meaningful long-term point of reference for some of the most important physical and biological processes, which unfold only after many decades, such as sea-level rise and changes in sediment supply. There is, however, substantially greater uncertainty regarding long-term forecasts in physical processes dependent on basic unknown variables such as the future changes in the rate of sea level rise, and sediment fluxes in the Estuary.

The interactions of geomorphic and hydrologic factors with other environmental factors, such as biological resources, recreational uses, water quality, human health and safety, and aesthetics are addressed in those respective sections.

ALTERNATIVE 1: Proposed Action/Proposed Project. Regional Eradication

IMPACT GEO-1: Erosion or deposition of sediment at sites of cordgrass eradication

The degree to which invasive cordgrass removal methods would result in sediment erosion or deposition depends on (1) the general background conditions of sediment deposition and erosion related to the environmental setting; (2) the method of removal; and (3) subsequent interactions with new vegetation following removal.

Removal of invasive Atlantic smooth cordgrass from diked baylands restored to tidal action is unlikely to cause significant net erosion of new sediment if cordgrass and sediment are not mechanically removed (e.g. dredged or excavated). Residual cordgrass dead below-ground root/rhizome networks, left after colonies are killed by methods such as impoundment, repeat mowing, or herbicide treatment, probably would persist long enough to temporarily stabilize most accreted sediment while new (native) vegetation establishes and permanently stabilizes the marsh. This is most likely to occur where Atlantic smooth cordgrass caused enough marsh accretion to reach tidal elevations at which perennial pickleweed readily establishes.

Where sediments are loosened by ripping, discing, excavation, or dredging they would be subject to rapid erosion in chronically high-energy tidal flats, but would probably suffer minor erosion or net topographic changes in most depositional or stable mudflat settings. In no circumstances would invasive cordgrass removal result in chronic, progressive net erosional trends compared with adjacent, uninvaded tidal habitats. Changes in erosional rates and patterns of mudflats caused by removal operations would usually be less than significant, but could be significant in some exposed shores with relatively high wave energy or high background erosion rates.

The long-term reduction in sediment accretion due to treatment is considered a beneficial effect. Increased erosion in tidally restored diked baylands following removal of invasive Atlantic smooth cordgrass would be less than significant.

Tidal creeks invaded by Atlantic smooth cordgrass are naturally subject to relatively concentrated, high velocity tidal currents compared with open marsh surfaces. Tidal creek banks and bed surfaces released from live Atlantic smooth cordgrass cover are likely to scour and erode, but resistance caused by residual below-ground growth is likely to restrict full recovery of pre-invasion tidal creek dimensions. Slow erosion allows time for other native vegetation to stabilize accreted sediment. If tidal creeks are cleared of Atlantic smooth cordgrass by excavation or dredging below the root zone, tidal creek dimensions are more likely to be restored by erosion. If tidal channels are over-excavated (dug below original surfaces), they may instead become temporarily depositional environments until equilibrium dimensions and forms are regenerated in the tidal creek. Tidal creeks typically undergo rapid (one- to three-year) cycles of erosion and accretion during and after major storms, and similar rapid cycles are likely to develop where sediment and vegetation are removed artificially. Erosion and deposition induced in tidal creeks that are greater in magnitude or persistence than that associated with typical storm cycles would be significant. In tidal creeks currently experiencing invasion by Atlantic smooth cordgrass, erosional effects would be beneficial (consistent with environmental objectives of eradication).

Mudflats invaded by Atlantic smooth cordgrass in most cases are relatively exposed to the force of wind-generated waves in the open bay. Here, removal of invasive cordgrass colonies would likely release any sediment deposited above the elevation of adjacent mudflats. Residual dead belowground cordgrass roots and rhizomes would be less effective in resisting wave erosion than tidal currents of small creeks within tidal marsh settings. If invasive cordgrass colonies were removed from mudflats by excavation or dredging below the level of the root zone, broad, shallow depressions would be formed. These broad topographic depressions would likely fill with sediments to approach the elevation of adjacent mudflats in sediment-rich, net depositional settings under moderate to low wave energy conditions. In exceptional cases, where invasive cordgrass colonies established on erosional or chronically high-energy mudflats (e.g. southern Hayward bayfront), depressions left by over excavation would probably persist or enlarge. All mudflats released from cordgrass cover would be restored to near natural levels of sediment mobility within months or years.

High marsh plains (at elevations near Mean Higher High Water) invaded by Chilean or salt-meadow cordgrass are likely to be rapidly recolonized by native dominant plants capable of rapid lateral spread such as saltgrass, jaumea, or pickleweed, which also readily establish from seed. Potential erosional forces are weaker on the higher marsh surface because of relatively infrequent tidal inundation, and cohesive properties of marsh soils with dense, mature root systems or peat accumulation. Impacts in these locations would be less than significant.

MITIGATION GEO-1: In sites of cordgrass removal where unacceptable increases in erosion rates (significantly greater than background levels or threatening the stability of existing infrastructure such as access roads or utility structures) are likely, temporary physical erosion controls shall be established until sediments either consolidate or stabilize naturally. In mudflats, revegetation as a stabilization measure is precluded because it would be infeasible or defeat the purpose of eradication. In some situations natural lag armor materials such as shell fragments (too heavy to be eroded) may be spread over erosion-susceptible surfaces such as excavation scars to increase resistance to further scour. Other standard erosion control methods for terrestrial environments (such as jute netting, silt fences, coir fabric, etc.) would be ineffective and unstable (rapidly removed) in energetic tidal environments, and could cause nuisances or hazards where they are redeposited. For tidal creeks, monitor following removal for return of adequate channel dimensions. If tidal creek banks require revegetation after adequate dimensions are restored by erosion, they shall be replanted with sprigs of native Pacific cordgrass.

IMPACT GEO-2: Erosion or topographic change of marsh and mudflat by vehicles used in eradication

Heavy equipment or vehicles working on marsh or mudflat surfaces are very likely to cause ruts in relatively soft, unconsolidated spots on the marsh, and on nearly all mudflats. For some treatment methods, ruts and visible tracks would be intentional. Ruts and ridges (small mudwaves) are likely to cause a maximum of about 30 to 40 centimeters of topographic relief, creating persistent local depressions that impound water from rainfall or high tides on the marsh plain. Ruts and ridges left on unstable mudflats are likely to revert to adjacent elevations by rapid erosion and deposition. The more sheltered the mudflats, the more persistent changes are likely to be. Heavy equipment working on mats is unlikely to cause erosion or topographic changes in tidal marshes, unless operational failure causes lodging or miring of vehicles and equipment off the mats. If this were to occur, it could be a potentially significant impact.

MITIGATION GEO-2: Unless the treatment method specifically requires it, vehicle travel in the tidal marsh and mudflat shall be minimized. Mats shall be used to distribute the weight of vehicles on marsh surfaces wherever feasible. Sensitive sites, or sites surrounded by sensitive habitat that could be significantly impacted by erosion or sedimentation from overland vehicles shall be accessed by boat providing those access methods have less overall adverse environmental impact.

IMPACT GEO-3: Remobilization of sand in cordgrass-stabilized estuarine beaches

Where Atlantic smooth cordgrass and hybrids are removed from former sand or shell beaches, wave energy and wave-generated currents would rework previously deposited and stabilized sand in the beaches. Longshore transport of sand would resume, allowing erosion and accretion patterns to re-establish new shoreline configurations similar to pre-invasion conditions. During storms, previously stabilized, vegetated beach ridges would develop erosional scarps and washover deposits, as well as typical smooth, unvegetated sand shorelines. During calm periods, seasonal ephemeral beach ridges would redeposit on the shoreward faces of eroded beach ridges. Where only above-ground invasive cordgrass mass has been removed (e.g. herbicide or repeat-cropping methods such as mowing), residual erosion resistance of killed roots and rhizome mats would retard remobilization of beaches. Where invasive cordgrass growth has been removed, net sediment loss to the beach system would occur unless it were replaced by natural or artificial deposition.

In most cases, remobilization of estuarine beaches would be a beneficial effect. However, in some cases, it may be possible for resumed sediment transport to reactivate detrimental erosion that was halted by cordgrass invasion. This could occur along developed or artificially stabilized shorelines where there has been a natural reduction or failure of sediment supply, or excess wave energy.

MITIGATION GEO-3: Resumed erosion at sensitive locations shall be mitigated by one or both of the following shoreline stabilization measures:

- Sand nourishment (artificial placement of suitably textured sand [appropriate grain size for local wave climates]) may be appropriate along relatively low-energy estuarine shorelines. Sand nourishment may be suitable if cordgrass is removed by excavation, leaving extensive temporary erosional scars and deficits in local sand budgets. Excavated cordgrass-infested sand could be stockpiled at upland or non-sensitive diked baylands long enough to desiccate and kill cordgrass rhizomes. When inert, it could be replaced in the foreshore to be made again available for waves to rework.
- Repair or replacement of rock slope protection or other existing erosion protection structures. It should be noted that these measures may result in secondary impacts on biological and other resources that would need to be analyzed in project-specific environmental reviews.

IMPACT GEO-4: Increased demand for sediment disposal and potential spread of invasive cordgrass via sediment disposal

Treatment activities involving large-scale removal of accreted sediments (for example, dredging) will result in the secondary impact of increased demand for disposal of dredge spoils. If these spoils were to be disposed of in bay or ocean dredge material disposal sites, viable invasive cordgrass seeds could be spread throughout the Estuary and to other coastal estuaries. This would be a significant adverse impact of the project.

MITIGATION GEO-4: Sediments dredged or otherwise removed from treatment sites shall be disposed of as prioritized in the Corps of Engineers' 1998 Long Term Management Strategy (LTMS) for Bay dredged material. These sediments shall not be disposed of in dredge disposal sites in the Estuary or offshore where seeds may be dispersed elsewhere in the Estuary or to other coastal estuaries. They shall be disposed of in upland disposal sites or at depths in sites proposed for tidal marsh restoration. If the latter approach is selected, cordgrass-contaminated sediments shall be overlain by at least two feet of sediments that are free of invasive cordgrass seed or other invasive cordgrass matter. Regional strategic coordination between eradication and tidal marsh restoration projects may also allow a synergy among multiple projects involving sediment removal (flood control, eradication) and sediment deposition (tidal marsh restoration in salt ponds).

IMPACT GEO-5: Increased volume and velocity of tidal currents in channels due to the removal of invasive cordgrass

With the elimination of channel friction created by tall, dense stands of Atlantic smooth cordgrass, tidal flows in channels would increase to rates similar to or greater than those that prevailed prior to invasion. Increased flows would also increase the efficiency of tidal drainage from marsh plains adjacent to treated creeks. This impact generally would be beneficial.

Secondary impacts of increased tidal volumes and velocities (erosion) are addressed in Impact GEO-1, above.

Mitigation Measures

None required.

IMPACT GEO-6: Increased depth and turbulence of tidewaters impounded in salt marsh pans

Where Atlantic smooth cordgrass and hybrids are removed from salt marsh pans or similar ponded depressions, elimination of the shelter provided by the foliage and stem canopy would subject the water surface to wind-stress currents and waves. The hydrology of these treated wetland areas would function as shallow ponds rather than shallowly flooded marsh. Residual below-ground biomass and residual accreted sediment in the pan bottom would tend to stabilize the bed and reduce the effect of restored turbulence on turbidity. If pans were excavated to remove invasive cordgrass, they would probably become slightly deeper than in natural conditions or pre-invasion conditions, and would be slow to accrete. Restoration of typical pan conditions would be a beneficial effect on wetland hydrology.

Mitigation Measures

None required.

ALTERNATIVE 2: Regional Eradication Using Only Non-Chemical Control Methods

Impacts

Impacts under the herbicide-free alternative would be similar to those described previously for Alternative 1, however additional repeated control activities would necessary under this alternative. In addition, this alternative would require a proportionally greater use of methods that would involve substrate disturbance (discing/shredding), excavation or dredging. Substrate disturbing methods would probably be required for eradication of tidal creek infestations in the absence of herbicide use. In some circumstances, methods that kill invasive cordgrass in place may substitute where herbicides would otherwise be most feasible or effective (e.g., smothering, impoundments within the marsh plain or tidally restored diked baylands, and repeat mowing or crushing). To the extent that dredging or other substrate-disturbing treatment methods are substituted for chemical applications, less dead below-ground cordgrass biomass would be left in place to bind sediments and resist or slow erosion rates, and erosion would be increased compared with Alternative 1.

For eradication work on mudflats and low marsh (which is the largest acreage category of the project, due to prevalence of *Spartina alterniflora* hybrids) the direct physical impacts of cordgrass removal are limited by the natural condition of unvegetated, unconsolidated bay mud of tidal flats. Even immediately after mechanical treatments such as tillage (discing) or excavation, substrate conditions would be consistent with the natural (though not pre-project) condition of unvegetated, unconsolidated mud. In context of naturally unvegetated conditions of mudflats, the intensity of this geomorphic impact would be insignificant. Most of the direct impacts would be biological (ecological) rather than physical. In the regulatory context of CEQA and NEPA, however, the reference condition is the existing invasion by non-native vegetation, not natural conditions. The most important indirect physical impacts of repeated mechanical treatment are likely to occur by access of equipment through the high and middle marsh zones. Here, too, ecological impacts (destruction of vegetation important to wildlife habitat) are relatively more important than purely physical effects. Even so, the incremental increase in damage to the marsh decreases after the first few passes of equipment, when most of the vegetation damage occurs. Prolonging the damage by repetition, rather than increasing its magnitude within an area, is a greater risk. Note also that some physical control methods, such as flooding/drowning, covering, and mowing, have minimal impacts to substrate, and long-term hydrologic impacts similar to any other method removing vegetation that provides bottom roughness (friction against water flow).

Mitigation Measures

Mitigations GEO-1 through GEO-4 would reduce this impact to less than significant levels.

ALTERNATIVE 3: No Action – Continued Limited, Regionally Uncoordinated Treatment

Impacts

Some of the ongoing and potential future effects of non-native cordgrass invasion are in early stages of development. Others are likely to develop only over many years or decades, and must be inferred by indirect evidence, comparison with analogous estuarine systems, and projected trends of current conditions.

The intertidal landforms of the San Francisco Estuary are currently being altered in areas where invasive cordgrasses have established. Most of the effects are due to Atlantic smooth cordgrass and its hybrids, which establish extensive colonies in the mudflats and channels (low marsh zone) of the Estuary. Atlantic smooth cordgrass is a potent geomorphic agent, and is widely used by coastal engineers to stabilize shorelines, increase local sedimentation, and other estuarine sediment deposits (Woodhouse 1979, Knutson and Inskeep 1982). Other invasive non-native cordgrasses of the low marsh, such as English cordgrass have potential to behave similarly. In contrast, invasive non-native cordgrasses of the higher marsh plain in the San Francisco Estuary, Chilean cordgrass and salt-meadow cordgrass, are likely to have more subtle effects on geomorphology and hydrology, because they have less direct exposure and interaction with tidal flows and sediments. Most of the following discussion focuses on the effects of the Atlantic smooth cordgrass hybrids.

Atlantic smooth cordgrass in its native salt marsh habitats can tolerate sediment accretion up to about 30 centimeters (one foot) per year (Zaremba 1982), and naturally establishes in estuarine "wave climates" (prevailing wave energy of a shoreline) far greater than those that support Pacific cordgrass (Newcombe *et al.* 1979). It is capable of stabilizing shorelines too exposed to support Pacific cordgrass (Knutson *et al.* 1982, Knutson and Woodhouse 1983). Its capacity to invade bare, poorly drained flats and pans (Bertness and Ellison 1987), and cover them with extensive stands of its mature "short form" is associated with the marked scarcity of the depressional tidal pools (salt pans) and lack of extensive, fine-scale tidal creek networks in the vast tidal marshes of the Atlantic coastal plain (Dame *et al.* 2000, Frey and Basan 1978). The relatively homogeneous salt marsh plains formed by Atlantic smooth cordgrass in most of its native range contrast with the complex tidal marsh topography (high density of sinuous creeks and pans) that is characteristic of San Francisco Estuary tidal marshes (Pestrong 1965).

In the Pacific Northwest (Willapa Bay), invasive Atlantic smooth cordgrass has progressively converted thousands of acres of tidal mudflat to single-species marsh plains, immobilizing underlying sediment, and increasing sedimentation rates within the areas it occupies. Rates of sedimentation under Atlantic smooth cordgrass depend in part on the local depositional environment (sediment supply, rates of transport), and cannot be generalized between regions, or even within tidal marsh systems. The capacity for a stand of Atlantic smooth cordgrass to increase sedimentation rate is also a function of stem density (number of stems per unit area) (Gleason, *et al.* 1979), which also corresponds with the density of the leaf canopy. The canopy height of Atlantic smooth cordgrass also is an important factor in damping wave energy and slowing currents, especially during higher tides.

On the basis of long-term development of Atlantic smooth cordgrass marshes in other estuaries, as described above, and actual observations of the early stages of the invasion in the San Francisco Estuary to date, the following geomorphic effects of this species' invasion are likely to increase as the invasion progresses.

Short-term impacts of this alternative would be similar to those described for the treatment methods for Alternative 1, however these impacts would be less widespread due to the anticipated smaller areas to be treated under this alternative.

This alternative assumes that the effectiveness of regionally uncoordinated, individual projects would be outpaced and overwhelmed by non-native cordgrass invasions within about a decade, allowing rates of spread to occur that do not effectively differ from a complete absence of eradication efforts in the region as a whole. In the short term, treatment impacts would be similar to those described above for Alternative 1. In the long term, about a decade, the invasion of non-native cordgrasses is expected to outpace control efforts to the extent that invasive cordgrass removal would be limited to that necessary to maintain essential flood control and navigational channels. Therefore, in the long-term, except for necessary flood control and navigational channel clearing, increased erosion at or near sites of cordgrass invasions would not occur as invasive cordgrass colonies coalesce to continuous marsh that resists erosion and promotes local deposition of sediment.

Evaluation of long-term effects of this alternative on tidal marshes requires long-range "forecasts" of marsh maturation. Reasonably reliable and realistic general, qualitative predictions about tidal marsh maturation can be made by geographic comparisons of observed long-term development of tidal marshes in other regions that have ecologically equivalent, or identical, major plant species as the San Francisco Estuary. Observations and scientific investigations of salt marshes influenced or dominated by the species of cordgrasses that are not native to the San Francisco Estuary provide guidance, but not certain knowledge, of the likely results of their spread in this region. Based on these observations and investigations, likely future scenarios of cordgrass invasion are variable and can best be viewed as alternative scenarios more or less likely to occur in the San Francisco Estuary.

The most optimistic scenario is one under which species that have been relatively slow to spread from established sites will continue to be poor long-distance invaders. Under this scenario, the most invasive species, such as Atlantic smooth cordgrass and its hybrids would become less "virulent" and aggressive over time as marshes mature, gradually dying out as marshes accrete, and becoming more intermediate with native cordgrass as the two species hybridize increasingly. This scenario is similar to the British salt marsh experience with English cordgrass where, after a century of invasion, dieback occurred spontaneously in some accreted marshes, and native salt marsh vegetation (but not the original mudflats) established.

There is little evidence that Atlantic smooth cordgrass is likely to behave in this way. In its native range, it is replaced in accreted northeastern Atlantic high salt marshes only by saltmeadow cordgrass, which itself is an invasive species in the San Francisco Estuary. In southeastern Atlantic salt marshes, smooth cordgrass dominates high marsh plains with its short form. Nowhere in its native range does perennial pickleweed (a minor associated species) replace it as dominant salt-marsh vegetation. Investigations of hybrid cordgrasses in San Francisco Bay do not support the hypothesis that natural selection is favoring the evolution of less invasive, slower-growing, native Pacific cordgrass-like hybrid intermediates. On the contrary, there appears to be a competitive advantage to more robust, smooth cordgrass--like hybrid forms. Thus, the optimistic scenario cannot be ruled out, but appears relatively unlikely.

Another relatively optimistic scenario would be that the invasive cordgrass species in this region can be confined to the San Francisco Estuary, and controlled by long-term maintenance (weeding) of existing infested marshes, short of regional eradication. Globally, there are no examples of benign naturalization of aggressively invasive cordgrasses, and no examples of stable long-term confinement. Efficient reproduction of cordgrasses in receptive habitats sustains a high potential for eruptive population spread.

A less optimistic, and more likely, scenario is that Atlantic smooth cordgrass progressively dominates the San Francisco estuary. Under this scenario, there is still much uncertainty about the likely future structure of intertidal habitats. If sea level rise continues to accelerate, while sediment supplies become more deficient, extensive low marsh cordgrass meadows with ample tidal drainage may form, and this would tend to favor tall forms of Atlantic smooth cordgrass. If sedimentation in the San Francisco Estuary is able to keep pace with sea level rise, there is a greater chance that higher marsh plains, with defined drainage patterns, may form. This would increase the risk that smooth cordgrass would behave as it does in the southeastern Atlantic salt marshes, where it forms extensive single-species stands of stunted, short-form cordgrass marsh, and limits the development of small tidal creeks and pans (features typical of Pacific and northeastern Atlantic high salt marsh).

Although all of the scenarios described above are possible, this last scenario is considered the most likely scenario and represents a "reasonable worst case". Under this scenario, it is reasonable to assume that pervasive or complete invasion would occur within a century, based on the history of other coastal non-native plant invasions in California and elsewhere (Cronk and Fuller 1995, Bossard *et al.* 2000). Overwhelming rates of spread by the hybrids would probably cause the extinction (or effective extinction) of *native* Pacific cordgrass in the San Francisco Estuary within a century after collapse of regional eradication. Individual eradication projects, such as selective removal of invasive cordgrass in individual marsh restoration sites or flood control channels, would have to accelerate maintenance schedules as invasion pressures (frequency of new colonies from dispersed seed) increase at an accelerating pace. Selective removal of non-native cordgrass at restoration sites would probably cease when monitoring confirms that no native cordgrass is recruited, and all spontaneous recruits are invasive species, even when natives are planted. Eradication for flood control purposes, however, may continue locally in perpetuity.

In the long term, increased sediment accretion, reduction in efficiency of tidal drainage, and reduced current velocities in channels would be likely, and would increase in magnitude and distribution over time. Shallow ponds would likely be converted to poorly drained marsh plain. Restored tidal marshes in formerly diked baylands would develop marsh topography similar to the salt marshes of the Atlantic coastal plain, forming relatively undifferentiated vegetated marsh plains. Rates of sediment supply to tidal marshes restored behind dikes may be constrained by the stabilization of mudflat sediment sources by invasive cordgrass, which would also intercept and trap significant volumes of potentially available tidal sediment. Most salt marsh pans would be assimilated into the marsh plain, and would not persist as distinct ponded features.

Mitigation Measures

Other than Alternatives 1 and 2, there are no feasible mitigation measures for these impacts of the spread of invasive cordgrasses.

Table 3.1-1: Summary of Potential Hydrologic and Geomorphic Effects

Impact	*Manual Removal (Hand pulling and manual excavation)*	*Mechanical Removal (Excavation, dredging, and shredding)*	*Pruning, Hand-mowing, and Smothering*	*Flooding (Diking, drowning, and salinity variation)*	*Burning*	*Herbicide Application*	*Beneficial Effects*
GEO-1: Erosion or deposition of sediment at sites of cordgrass eradication.	All Alternatives: Minor erosion and sedimentation.	All Alternatives: Potentially significant erosion.	All Alternatives: Minor erosion potential.	All Alternatives: Potentially significant erosion from diking activities.	All Alternatives: Minimal erosion potential.	All Alternatives: Minor erosion potential.	Alternatives 1, 2: Beneficial effect on sediment transport in tidal creeks, mudflats, marshes, and channels.
GEO-2: Erosion or topographic change of marsh and mudflat by vehicles used in eradication.	All Alternatives: Minor impact from access.	All Alternatives: Potentially significant microtopographic changes and erosion from use of vehicles in marshes.	All Alternatives: Minor impact from access.	All Alternatives: Potentially significant topographic changes from diking activities.	All Alternatives: Minor impact from access.	All Alternatives: Minor impact from access.	N/A
GEO-3: Remobilization of sand in cordgrass-stabilized estuarine beaches.	All Alternatives: Minor increased beach erosion and sedimentation.	All Alternatives: Potentially significant erosion.	All Alternatives: No impact.	All Alternatives: Potentially significant beach erosion.	All Alternatives: Potentially significant beach erosion.	All Alternatives: Potentially significant beach erosion.	Alternatives 1,2: Long-term benefit of establishment of beaches. Alternative 3: Short-term benefit to beach restoration, no long-term benefit.

Table 3.1-1: Summary of Potential Hydrologic and Geomorphic Effects

Impact	*Manual Removal (Hand pulling and manual excavation)*	*Mechanical Removal (Excavation, dredging, and shredding)*	*Pruning, Hand-mowing, and Smothering*	*Flooding (Diking, drowning, and salinity variation)*	*Burning*	*Herbicide Application*	*Beneficial Effects*
GEO-4: Increased demand for sediment disposal and potential spread of invasive cordgrass via sediment disposal.	All Alternatives: No impact.	All Alternatives: Potentially significant impacts related to disposal of dredged sediments and inadvertent dispersal of invasive cordgrass via disposed sediments.	All Alternatives: No impact.	All Alternatives: No impact.	All Alternatives: No impact.	All Alternatives: No impact.	All Alternatives: No impact.
GEO-5: Increased volume and velocity of tidal currents in channels due to the remoal of invasive cordgrass.	All Alternatives: Minor impact from localized clearing.	All Alternatives: Potential increase in erosion from increased tidal velocities/currents.	All Alternatives: No impact.	All Alternatives: Potential increase in erosion from increased tidal velocities/currents.	All Alternatives: Potential increase in erosion from increased tidal velocities/ currents.	All Alternatives: Potential increase in erosion from increased tidal velocities/currents.	All Alternatives: Beneficial effect on tidal channel and creek flows.
GEO-6: Increased depth and turbulence of tidewaters impounded in salt marsh pans.	All Alternatives: No adverse impacts. .	All Alternatives: No adverse impacts.	All Alternatives: No adverse impacts.	All Alternatives: No adverse impacts.	All Alternatives: No adverse impacts.	All Alternatives: No adverse impacts.	Alternatives 1, 2: Permanent beneficial effect. Alternative 3: Temporary beneficial effect.

Table 3.1-2: Summary of Mitigation Measures for Hydrology and Geomorphology

Mitigation	*Manual Removal (Hand pulling and manual excavation)*	*Mechanical Removal (Excavation, dredging, and shredding)*	*Pruning, Hand-mowing, and Smothering*	*Flooding (Diking, drowning, and salinity variation)*	*Burning*	*Herbicide Application*
Mitigation GEO-1: Erosion or deposition of sediment. In sites of cordgrass removal where unacceptable increases in erosion rates (significantly greater than background levels or threatening the stability of existing infrastructure such as access roads or utility structures) are likely, temporary physical erosion controls shall be established until sediments either consolidate or stabilize naturally.	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable
Mitigation GEO-2: Erosion or topographic change by vehicles used in eradication. Vehicle travel in the tidal marsh and mudflat shall be minimized. Mats shall be used to distribute the weight of vehicles on marsh surfaces wherever feasible. Sensitive sites that could be significantly impacted by erosion or sedimentation from overland vehicles shall be accessed by boat.	Not Applicable	Applicable	Not applicable	Not Applicable	Applicable	Applicable
Mitigation GEO-3: Remobilization of sand. Resumed erosion at sensitive locations shall be mitigated by sand nourishment or repair or replacement of existing rock slope protection or existing erosion control structure.	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable
Mitigation GEO-4: Sediment disposal. Sediments dredged from treatment sites shall be disposed of as prioritized in the Long Term Management Strategy for Bay dredged material. These sediments shall not be disposed of in dredge disposal sites in the Estuary or offshore where seeds may be dispersed elsewhere in the Estuary or to other coastal estuaries. They shall be disposed of in upland disposal sites or at depths in sites proposed for tidal marsh restoration.	Not Applicable	Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable

Note: There may be textual differences between the measures in this summary table and the text in the section. The actual mitigation measure is in the text.