Aquatic Pesticide Application Plan
for the
San Francisco Estuary Invasive *Spartina* Project

This plan addresses herbicide application activities undertaken by
ISP Partner agencies in the effort to eradicate non-native, invasive *Spartina*
from the San Francisco Estuary.

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1. BACKGROUND

The San Francisco Bay Estuary (San Francisco Estuary or Estuary) supports the largest and most ecologically important expanses of tidal mudflats and salt marshes in the contiguous western United States. This environment naturally supports a diverse array of native plants and animals. Over the years, many non-native species of plants and animals have been introduced to the Estuary, and some now threaten to cause fundamental changes in the structure, function, and value of the Estuary's tidal lands. Among these threatening invaders are several species of salt marsh cordgrass (genus *Spartina*). In recent decades, populations of non-native cordgrasses were introduced to the Estuary and began to spread rapidly. Though valuable in their native settings, these introduced cordgrasses are highly aggressive in this new environment, and frequently become the dominant plant species in areas they invade.

One of the non-native cordgrass species, Atlantic smooth cordgrass (*Spartina alterniflora*), is rapidly spreading throughout the Estuary, particularly in the South San Francisco Bay (South Bay). Atlantic smooth cordgrass and its hybrids (formed when this species crosses with the native Pacific cordgrass, *S. foliosa*) are now threatening the ecological balance of the Estuary. Based on a century of international studies of comparable cordgrass invasions, these hybrids are likely to eventually cause the extinction of native Pacific cordgrass, choke tidal creeks, dominate newly restored tidal marshes, and displace thousands of acres of existing shorebird habitat. Once established in this estuary, invasive cordgrasses could rapidly spread to other estuaries along the California coast through seed dispersal on the tides. Non-native invasive cordgrasses currently dominate approximately 1,200-1,500 acres of the San Francisco Estuary in seven counties — on State, Federal, municipal, and private lands— and are spreading at an alarming rate.

The California State Coastal Conservancy (Conservancy) initiated the ISP in 2000 to stave off the invasion of non-native cordgrass and its potential impacts. The ISP is a regionally coordinated effort of Federal, State, and local agencies, private landowners, and other interested parties, with the ultimate goal of arresting and reversing the spread of non-native cordgrasses in the San Francisco Estuary. When fully implemented, the ISP will provide opportunities to maximize resources, effectively disseminate information, facilitate regional monitoring, and reduce the occurrence of cordgrass re-infestation. The geographic focus of the ISP includes the nearly 40,000 acres of tidal marsh and 29,000 acres of tidal flats that comprise the shoreline areas of the nine Bay Area counties, including Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma Counties, and Sacramento County.

2. STATEMENT OF PURPOSE AND NEED

The purpose of the *Spartina* control program is to arrest and reverse the spread of invasive non-native cordgrass species in the San Francisco Estuary to preserve and restore the ecological integrity of the Estuary's intertidal habitats and estuarine ecosystem.

The *Spartina* control program is needed to prevent further degradation and loss of the natural ecological structure and function of the San Francisco Estuary. In the absence of any coordinated and wide-ranging control program, within decades one-quarter to one-half (up to 10,000 acres) of the existing intertidal flats are likely to be replaced with dense, invasive cordgrass marsh, and much of the native diverse salt-marsh vegetation replaced with nearly homogeneous stands of non-native cordgrass. This ecological conversion is likely to alter the structure and function of the Estuary, affecting fisheries, migratory shorebirds and waterfowl, marine mammals, endangered fish, wildlife, and plants, tidal sediment transport, and the rate, pattern, and magnitude of tidal flows. In addition, invasive cordgrasses may impede or preclude plans to restore up to 20,000 acres of diked baylands to native tidal marsh. Arresting and reversing the invasion of non-native cordgrasses may not be feasible once these species have spread and become established, due to the expansive scale of the invasion and the effects of hybridization. To avoid these consequences, the ISP is implementing a regionally coordinated, long-term management program.

3. DESCRIPTION OF THE WATER BODY SYSTEM

Ecology

Like most Pacific estuaries, the majority of the intertidal zone of the San Francisco Estuary naturally consists of unvegetated tidal flats, or mudflats. Native California tidal marsh vegetation is limited to the upper intertidal zones, above mean sea level in San Francisco and San Pablo Bays. Below mean sea level, waves erode and redeposit the upper layers of bay mud with each tidal cycle. Rich deposits of fine silt and clay from the Sacramento-San Joaquin Delta have accumulated in the Estuary to form highly productive mudflats, with abundant benthic invertebrates. The mudflats provide a critical source of nutrition and energy for migratory shorebirds and waterfowl, with more than one million shorebirds using the Estuary's mudflats and salt ponds during migration, and over half of the west-coast migratory diving ducks making this estuary their winter home.

At elevations above the intertidal zone (in areas that have not been diked and removed from tidal action), are the Estuary's tidal salt and brackish marshes. Pacific salt marsh vegetation is more diverse in plant species than its Atlantic counterparts. Until recent decades, the native Pacific cordgrass exclusively occupied the lower reaches of the Estuary's tidal salt marshes. At slightly higher elevations, a relatively flat tidal marsh plain (reaching near the average level of the higher daily tides), is dominated by low-growing, mostly perennial plants such as pickleweed, saltgrass, and other salt-tolerant herbs. The tidal marsh plain is punctuated by salty shallow ponds (pans), and dissected by irregular tidal creeks. Above the tidal marsh plain, at the uppermost edges of the marsh, are an even greater number of plant species.

Many endemic (unique to the area) plant and animal species, including many rare or endangered species, survive only in the Estuary's remaining tidal marshes. They remain at risk of extinction because of the severe decline over the past century in the abundance, distribution, and quality of tidal marshes. Most of the Estuary's rare species have narrow or specific habitat requirements, and the health of their populations usually is sensitive to structural changes in their habitats - particularly the condition of the marsh vegetation. Strong dominance of the vegetation by one or more plant species necessarily results in lower overall species diversity, and can push rarer species to local extinction.

Natural Processes Affecting Water Quality

Water quality within the San Francisco Estuary is connected to and affected by complex regional and local natural processes. Hydrologic relationships between the Pacific Ocean, the Estuary, and the many freshwater tributaries (including the Sacramento-San Joaquin River system) govern salinity levels in different portions of the Estuary and along the Bay margins. Variable natural factors such as tidal cycles, local winds, basin bathymetry, and salinity gradients interact with river flows and affect the circulation of Estuary waters through channels, Estuary margins, and bays, distributing nutrients, salt concentrations, and pollutants. Major processes affecting water quality are described below.

Tidal Cycles. The Estuary has two low tides and two high tides every 24.8 hours. During each tidal cycle, an average of about 1.3 million acre-feet of water, or 24 percent of the Bay and Delta's volume, moves in and out of the Golden Gate. On the flood (incoming) tide, ocean water moves through the Golden Gate and into the Estuary's southern and northern reaches, raising the water level at the end of the South Bay by more than eight feet, and raising the height of the Sacramento River at the upstream edge of the Estuary by about three feet. It takes about two hours for the flood tide to reach the end of the South Bay and eight hours to reach Sacramento.

Subregional Conditions. Suisun and North Bay subregions receive the majority of freshwater input from the Sacramento and San Joaquin River system. In the open bays, density-driven currents show ebb dominance of the surface water and flood dominance of the bottom water. Waters in these embayments are well oxygenated, with low- to moderate-salinity and high-suspended solids concentrations. Water residence time affects the abundance and distribution of many estuarine organisms, the amount of primary production by phytoplankton, and some of the chemical and physical processes that influence the distribution and fate of pollutants. During low flow periods of the year (late summer), the residence time of freshwater moving from the Delta to the ocean can be relatively long (on the order of months) compared to periods when outflow is very high (winter), when freshwater can move from the Delta to the ocean in days.

The Central Bay subregion is influenced by ocean waters that are cold, saline, and lower in total suspended sediment. Water quality parameters fluctuate less than in other sectors of the Bay due to the predominance of ocean water. Net exchanges of ocean and Bay waters depend on freshwater flow in the Bay, tidal amplitude, and longshore coastal currents.

The southern part of San Francisco Bay receives less than 10 percent of the natural freshwater flow into the Bay, but the majority (>75 percent) of wastewater discharges. The largest flow is from San Jose, where approximately 120 million gallons per day (MGD) of treated wastewater are released into Artesian Slough, a tributary to Coyote Creek (Figure 1). This fresh water flow creates a local zone of brackish water in the otherwise saline tip if the South Bay. The rest of the South Bay, because it has so little freshwater input, is essentially a tidal lagoon with a relatively constant salinity (approximately the same as ocean water, 32 parts per thousand, ppt). South Bay waters are influenced by Delta outflow only during the winter months, when low-salinity water moves southward into the southern reach displacing the saline, denser water northward. In the summer months, however, South Bay currents are largely influenced by wind stress on the surface; northwest winds transport water in the direction of the wind, and the displaced water causes subsurface currents to flow in the opposite direction.

Currents and Circulation. Circulation patterns within the Bay are influenced by Delta inflows, gravitational currents, and tide- and wind-induced horizontal circulation. The cumulative effects of the latter three factors on net circulation within embayments tend to dominate over that of freshwater inflows except during short periods after large storm events (Smith 1987). Exchanges between embayments are influenced both by mixing patterns within embayments and by the magnitude of freshwater inflows (Smith 1987).

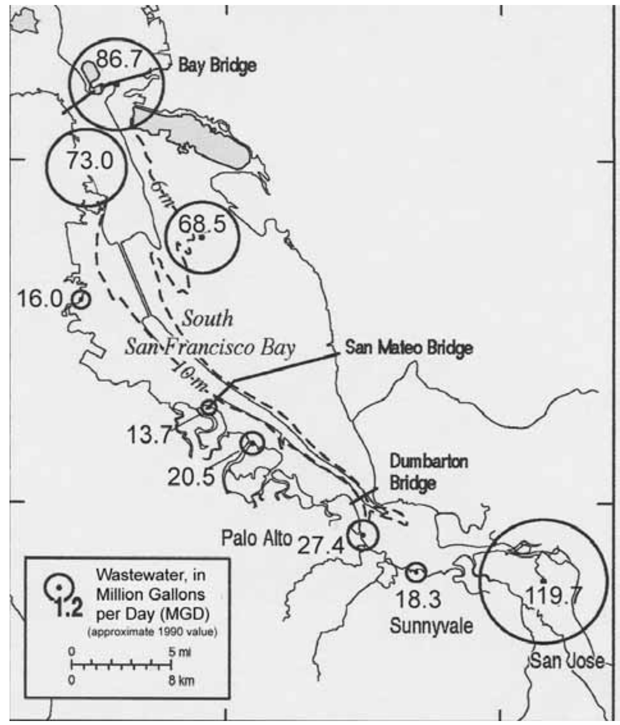

Figure 1. Locations and mean discharges for municipal wastewater treatment plants in South San Francisco Bay. Adapted from Schemel et al. 1999, based on Davis et al. 1991.

Currents created by tides, freshwater inflows, and winds cause erosion and transport of sediments. Tidal currents are usually the dominant form of observed currents in the Bay. Tidal currents are stronger in the channels and weaker in the shallows (Cheng and Gartner 1984). These processes enhance exchange between shallows and channels during the tidal cycle, and contribute significantly to landward mixing of ocean water and seaward mixing of river water. Also, the South Bay begins flooding while San Pablo Bay is still ebbing, making it possible for the South Bay to receive water from the northern reach (Smith 1987).

Tides have a significant influence on sediment resuspension during the more energetic spring tide when sediment concentrations naturally increase, and particularly during the ebbs preceding lower low water when the current speeds are highest. Powell *et al.* (1989), however, observed no correlation between tidal cycle and suspended sediment loads or distribution in the South Bay. Their conclusion was that winds are the most important factor in resuspending sediments in the South Bay, and that sources of sediments are more important than transport of sediment resuspended from other parts of the Bay (Reilly *et al.* 1992).

Wind-induced currents have a significant effect on sediment transport by resuspending sediments in shallow waters (Krone 1979; Cloern *et al.* 1989). An estimated 100 to 286 million cubic yards of sediments are resuspended annually from shallow areas of the Bay by wind-generated waves (Krone 1974; SFEP 1992b).

Water Quality

Water quality in the San Francisco Estuary has improved significantly since the enactment of the California Water Quality Control Act (Porter-Cologne) in 1969 and the Clean Water Act in 1972. Nevertheless, the Estuary waters still carry significant loads of pollutants from human sources. Under Section 303(d) of the Clean Water Act, states were required to develop a list of water bodies that do not meet water quality standards; this list is referred to as the "303(d) list." This list defines low, medium, and high priority pollutants that require immediate attention by State and Federal agencies. Portions of the Estuary have high-priority 303(d) listings for a number of pollutants, including dioxin compounds, furan compounds, PCBs, mercury, copper, nickel, and exotic (plant and animal) species.

The most comprehensive information describing water quality in the Estuary comes from the Regional Monitoring Program managed by the San Francisco Estuary Institute (SFEI) and ongoing studies by the Interagency Ecological Program (IEP). In addition, numerous short-term studies that focus on specific sites, resources, or pollutants are conducted on a regular basis by researchers and entities conducting permit-specified monitoring of waste discharges. The primary water quality parameters discussed below are: temperature, salinity, dissolved oxygen (DO), pH, total suspended solids (TSS), turbidity, and pollutants.

Temperature. Water temperatures in the Estuary range from approximately 10˚C to 22˚C (50˚F to 71.6˚F). Temperatures are influenced by seasonal solar cycles and variable inputs of river and coastal ocean waters. Temperatures are typically at the higher end of this range along the Estuary margin during daylight hours as the influence of solar energy warms the water.

Salinity. The salinity of the Estuary varies spatially and temporally. Along the northern reach the salinity increases from the Delta to the Central Bay. At the mouth of the Sacramento River, for example, the mean annual salinity averages slightly less than 2 ppt; in Suisun Bay it averages about 7 ppt; and at the Presidio in Central Bay it averages about 30 ppt. In the South Bay, salinities remain at near-ocean concentrations (32 ppt) during much of the year, except in the vicinity of the San Jose wastewater outfall at Artesian Slough, where salinities are less concentrated. During summer months in dry years, high evaporation rates may cause salinity in South Bay to exceed that of ocean water.

Seasonal changes in the salinity distribution within the Estuary are controlled mainly by the exchange of ocean and Estuary water, and by river inflow. River inflow has the greater influence on salinity distribution throughout most of the Estuary because inflow varies widely, while variations in ocean inputs are relatively small. In winter, high flows of freshwater from the Delta lower the salinity throughout the Estuary's northern reach. High Delta flows also intrude into South Bay, lowering salinity there for extended periods. In contrast, during the summer, when freshwater inflow is low, saline water from the Bay intrudes into the Delta. The inland limit of salinity intrusion varies greatly from year to year. In addition, channel dredging can increase gravitational circulation and enhance salinity intrusion (Nichols and Pamatmat 1988).

Dissolved Oxygen. Oxygen concentrations in estuarine waters are increased by the mixing action of wind, waves, and tides; photosynthesis of phytoplankton and other aquatic plants; and high DO in freshwater inflow. DO concentrations are lowered by plant and animal respiration, chemical oxidation, and bacterial decomposition of organic matter.

The Estuary's waters are generally well oxygenated, except during summer in the extreme southern end of the South Bay where concentrations are reduced by poor tidal mixing and high water temperature. Typical concentrations of DO range from 9 to 10 milligrams per liter (mg/l) throughout the Estuary during periods of high river flow, 7 to 9 mg/l during moderate river flow, and 6 to 9 mg/l during the late summer months when flows are the lowest. Unlike the 1950s and 1960s, when inadequately treated sewage and processing plant wastes depleted oxygen in parts of the Bay and Delta, today there are few reports of places in the Estuary where low oxygen concentrations adversely affect beneficial uses. Today, the lowest concentrations in the Estuary are typically observed in the extreme South Bay but, in some instances, DO levels in semi-enclosed embayments such as Richardson Bay can be much lower than in the main water body (SFEI 1994).

pH. The pH of the water in San Francisco Bay is relatively constant and typically ranges from 7.8 to 8.2[1].

Total Suspended Solids (TSS) and Turbidity. Turbidity and TSS are generally used as measures of the quantity of suspended particles. The distinction between the two terms lies mainly in the method of measurement. In general, higher TSS results in more turbid water.

Regions of maximum suspended solids occur in the North Bay in the null zone[2] (generally 50 to 200 mg/l, but as high as 600 mg/l TSS). The specific location of the null zone changes depending upon freshwater discharge from the Delta. TSS levels in the Estuary vary greatly depending on the season, ranging from 200 mg/l in the winter to 50 mg/l in the summer (Nichols and Pamatmat 1988; Buchanan and Schoellhamer 1995). TSS also varies with tidal stage and depth (Buchanan and Schoellhamer 1995). Shallow areas and channels adjacent to shallow areas have the highest suspended sediment concentrations. The Central Bay generally has the lowest TSS concentrations; however, wind-driven wave action and tidal currents, as well as dredged material disposal and sand mining operations cause elevations in suspended solids concentrations throughout the water column.

Pollutants. Pollutant loading to San Francisco Bay has long been recognized as one of many factors that has historically stressed aquatic resources. Pollutants enter the aquatic system through atmospheric deposition, runoff from agricultural and urbanized land, and direct discharge of waste to sewers and from industrial activity.

The Bay's sediment can be both a source and a sink for pollutants in the overlying water column. The overall influx of pollutants from the surrounding land and waste discharges can cause increases in sediment pollutant levels. Natural resuspension processes, biological processes, other mechanical disturbances, dredging, and sediment disposal can remobilize particulate-bound pollutants.

Metals. Ten trace metals in the aquatic system and in waste discharged to the Bay are monitored on a regular basis. Total and dissolved fractions are sampled three times a year at Regional Monitoring Program (RMP) stations throughout the Estuary. Tables 1 and 2 present dissolved and total trace metal concentration ranges in Bay waters during 1998 (SFEI 1998).

Organic Pollutants. Three general types of trace organic contaminants, polycylic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and pesticides, are measured in San Francisco Bay water on a regular basis.

1 Water or solutions that are acidic have a pH of less than 7.0, and basic or alkaline water have a pH greater than 7.0. A pH of 7.0 is considered neutral.

2 The null zone is area or region of an estuary where the bottom, high-density and surface, low-density currents have equal and opposite effects. It is defined as the zone where the mean near-bottom speed is zero. The actual location of the null zone migrates in response to changes in river discharge. It is important because it is typically characterized by high concentrations of suspended particulate matter and rapid sediment accumulation.

Water column concentrations of dissolved and total PAHs in 1998 ranged from 2.1 to 46 parts per trillion (pptr) and from 20 to 300 pptr, respectively (SFEI 1998). Total PCB concentrations in Bay waters during 1998 ranged from 70 to 7,000 parts per quadrillion (ppq), and were below the U.S. Environmental Protection Agency (U.S. EPA) 4-day (chronic toxicity) water quality criteria (30 pptr) (SFEI 1998). Dissolved PCB concentrations ranged from 12 to 930 ppq. Bay waters also contained measurable concentrations of chlorinated pesticides, including chlordanes and DDTs. Total chlordane concentrations ranged from 21 to 5,700 ppq, while total DDT concentrations ranged from 190 to 9,900 ppq (SFEI 1998).

A recent review of historical data from several sources found several previously unidentified organic contaminants in the San Francisco Estuary (SFEI 2002). In this study, p-nonylphenol, a common constituent in detergents and other household products, agricultural surfactants, and many industrial products, was identified in Sacramento and San Joaquin River water (at 19 ng/L and 5 ng/L, respectively), but it was not detected in Estuary water.

Sediment Quality

Sediment quality in the Estuary varies greatly according to the physical characteristics of the sediment, proximity to historical waste discharges, the physical and chemical condition of the sediment, and sediment dynamics that change with location and season. Generally, the level of sediment contamination at a given location will vary depending on the rate of sediment deposition, which varies with seasons and tides (Luoma *et al.* 1990). Chemical contaminant dynamics in an estuary are closely associated with the behavior of suspended and deposited sediments. The physical and chemical characteristics of sedi-

Table 1. Dissolved Concentrations of Trace Metals in Water Samples (SFEI 1998)

	Ag *µg/L*	*As* *µg/L*	*Cd* *µg/L*	*Cr* *µg/L*	*Cu* *µg/L*	*Hg* *µg/L*	*Ni* *µg/L*	*Pb* *µg/L*	*Se* *µg/L*	*Zn* *µg/L*
Minimum	0.0002	0.83	0.003	0.09	0.37	0.0003	0.56	0.002	ND	0.07
Maximum	0.006	4.8	0.09	3.8	3.5	0.015	7.2	0.40	6.1	22.5
WQ Criteria 1-hour	1.9	69	42	1100	5		74	210		90
WQ Criteria 4-day		36	9.3	50	3.1		8.2	8.1		81

ND – Not detectable at laboratory limits

Table 2. Total Concentrations of Trace Metals in Water Samples (SFEI 1998)

	Ag *µg/L*	*As* *µg/L*	*Cd* *µg/L*	*Cr* *µg/L*	*Cu* *µg/L*	*Hg* *µg/L*	*Ni* *µg/L*	*Pb* *µg/L*	*Se* *µg/L*	*Zn* *µg/L*
Minimum	0.002	ND	0.009	0.29	0.42	0.0006	0.63	0.05	ND	0.77
Maximum	0.20	9.4	0.36	101	20	0.73	49.0	15.8	6.8	98.6
WQ Criteria 1-hour	2.3	69	43	1100		2.1		140		58
WQ Criteria 4-day		36	9.3	50		0.025	7.1	5.6		

ND – Not detectable at laboratory limits ments, and the bioavailability and toxicity of sediment-associated chemicals to aquatic organisms, are particularly important in determining their potential impact on environmental quality.

While pollutant loading to the Estuary from point and non-point sources has declined dramatically over the past two decades, and surface sediment contamination may be declining from historical highs, Bay sediments are still an important source and sink of pollutants. Much of the data documenting concentrations of trace metals and organics in Bay sediments are found in the historical summary of Long and Markel (1992) and in the more recent monitoring efforts by the State's Bay Protection and Toxic Cleanup Program (BPTCP) (SFBRWQCB 1994) and Regional Monitoring Program (SFEI 1994 and 1998).

Concentrations of Metals and Organic Pollutants in Sediments. Mean concentrations of trace metals and organics in sediments vary according to grain size, organic carbon content, and seasonal changes associated with riverine flow, flushing, sediment dynamics, and anthropogenic inputs. Anthropogenic inputs appear to have the greatest effect on sediment levels of copper, silver, cadmium, and zinc, as well as several chlorinated and petroleum hydrocarbons (SFBRWQCB 1994). Ranges in sediment metals and trace organic concentrations during 1998 are listed in Table 3. The table also compares measured concentrations to effects range-low (ER-L) and effects range-median (ER-M) values, which are levels that are rarely associated with adverse effects to benthic organisms from exposures to sediment-associated contaminants and levels that are frequently associated with adverse impacts, respectively (Long *et al.*, 1995). For most pollutants, ranges in

Table 3. Ranges of Trace Pollutants in San Francisco Bay Sediments (SFEI 1998)

	Sediment Samples (mg/kg)		Effects Levels (mg/kg)	
	Minimum	*Maximum*	*ER-L*	*ER-M*
Arsenic	3.1	**19**	8.2	70
Cadmium	0.1	**2.1**	1.2	9.6
Chromium	63	**216**	81	370
Copper	8.5	**76**	34	270
Lead	5.4	**65**	46.7	218
Mercury	0.03	<u>**0.82**</u>	0.15	0.71
Nickel	**68**	<u>**228**</u>	20.9	51.6
Selenium	0.06	0.52		
Silver	ND	2.0	1.0	3.7
Zinc	64	**256**	150	410
Total PAHs	0.033	**6.30**	4.022	44.792
Total PCBs	ND	**0.26**	0.0227	0.18
Total DDTs	No Data		0.00158	0.0461
Total Chlordanes	ND	<u>**0.0099**</u>	0.0005	0.006

Key: Concentrations bolded exceed the Lowest Observable Effects Level (ER-L)
Concentrations bolded and underlined exceed the Median Observable Effects Level (ER-M)
ND – Not detectable at laboratory limits

measured concentrations exceed the respective ER-L values but are below the corresponding ER-M values. The exceptions are mercury, nickel, total PCBs, and total chlordanes, which exceed the ER-M values at one or more locations in the Bay. Some sites within San Francisco Bay, such as Lauritzen Canal, the Port of Oakland near San Leandro Bay, and Richmond Harbor, which have been greatly affected by historical contamination, contain sediment pollutant levels which are considerably higher than those measured by the Regional Monitoring Program.

4. DESCRIPTION OF TARGET SPECIES

There are one native and four non-native species of cordgrass in the San Francisco Estuary. The native species is Pacific cordgrass (*S. foliosa*), which is not a target of the ISP's control efforts, and is actually the recipient of conservation by controlling the invasive species). The non-native species are Atlantic smooth cordgrass (*S. alterniflora),* English cordgrass (*S. anglica),* Chilean cordgrass (*S. densiflora),* and salt-meadow cordgrass (*S. patens).* The non-native Atlantic smooth cordgrass hybridizes with the native Pacific cordgrass, and their offspring (referred to in this APAP as "Atlantic smooth cordgrass hybrids" or "hybrids") are highly invasive and considered non-native. Key aspects of the cordgrass species found in the Estuary are contrasted below. The biological contrasts among these species and their roles in their native habitats help to demonstrate how non-native cordgrasses are likely to alter the Estuary's salt marsh ecosystem. First described is the native Pacific cordgrass, followed by the non-native species.

Native Pacific Cordgrass (*Spartina foliosa*)

The historic range of Pacific cordgrass was confined to estuaries from Point Reyes to Baja California, with large gaps in between; for example, it is historically absent in Monterey Bay and Morro Bay. Most of the Pacific cordgrass population exists in San Francisco and San Pablo Bays. Its northern limit is now Bodega Bay, a small and recent natural population. It even more recently established in Tomales Bay, where its population surged following major flood and depositional events of the mid-1990s. Pacific cordgrass is a perennial, salt-tolerant marsh grass, which spreads both sexually, by seed dispersal, and asexually, by long, creeping rhizomes (underground stems, or runners) that propagate small clusters of leafy shoots. Clonal (asexual) growth of rhizomes allows individual plants to form extensive colonies without being pollinated by another plant. A colony thus formed is referred to as a "clone." The slender leafy shoots with seed-heads seldom exceed five feet in height, and most shoots range from about one to three feet tall. The height of the cordgrass plant is related to how well it tolerates submersion in tidewaters, and thus how low in the intertidal zone it can grow. The relatively short stature of Pacific cordgrass corresponds with its limited occupation of lower elevations within the intertidal zone.

Pacific cordgrass is genetically very similar to Atlantic smooth cordgrass, but the two species also have significant differences. In size, growth rate, production, and ecological tolerances, Pacific cordgrass is much less robust than Atlantic smooth cordgrass (Smart and Barko 1978, Callaway 1990, Boyer, Callaway and Zedler 2000). Pacific cordgrass grows more luxuriantly in clayey mud than sand, but it naturally grows in substrates ranging from sand and mud to peat. Its leaves and stems wither in fall and are shed in winter, as the clones die back to young shoots and buds near the mud surface. The sparse remains of Pacific cordgrass stands in winter are relatively ineffective in trapping sediment.

Pacific cordgrass is generally restricted to a narrow portion of the intertidal zone, between an elevation just above mean sea level and an elevation near the level of the average higher daily tide (mean higher high water, "MHHW"). It tends to fail in competition with plants like pickleweed on the marsh plain, which, in California estuaries, approaches the elevation of the MHHW. This modest range in tidal elevation restricts Pacific cordgrass to the sloping banks of tidal creeks, and the gently sloping upper edges of mudflats where sediment accumulates. This leaves the vast acreages of Pacific tidal flats below mean sea level entirely free of emergent vegetation in natural historic conditions. The vegetated marsh plain (middle to high marsh zone) supports either sparse Pacific cordgrass in lower areas, or none at all.

Early experiments with Pacific cordgrass demonstrated that its slender, widely spaced leafy shoots and rhizomes are not as effective at stabilizing sediment compared with Atlantic smooth cordgrass, especially under exposed conditions at the bay's edge (Newcombe et al. 1979). Seedlings of Pacific cordgrass are seldom found in established marshes, and appear only intermittently in sheltered upper mudflats.

Pacific cordgrass is particularly valued as habitat for the endangered California clapper rail, which spends most of its time foraging for food within, or close to, the protective canopy of cordgrass. Rails can move within Pacific cordgrass stands, and spend most of their time under cover of the cordgrass foliar canopy, usually selecting prey items such as invertebrates inhabiting the cordgrass stands and their edges. In contrast to the clapper rail of southern California tidal marshes, San Francisco Bay clapper rails generally do not construct "floating nests" in Pacific cordgrass; instead, they tend to build nests in gumplants or pickleweed in the higher marsh.

Atlantic Smooth Cordgrass (*Spartina alterniflora*) and its Hybrids

Smooth cordgrass is the closely related sibling to Pacific cordgrass. In the United States, it occurs along both the Atlantic and Gulf Coasts (Gleason and Cronquist 1991). It is unique among the world's cordgrass species in terms of its growth potential and ecological breadth, and it is the parent species of the other most invasive cordgrass species of hybrid origin, English cordgrass (*S. anglica*; Adam 1990). The San Francisco Estuary population of Atlantic smooth cordgrass was founded by seed from Maryland in the mid-1970s, introduced experimentally for one of the first tidal marsh restoration projects on the west coast. We refer to the San Francisco Bay population of smooth cordgrass as Atlantic smooth cordgrass.

Atlantic smooth cordgrass is a coarse perennial grass that, like its Pacific relative, spreads both by seed dispersal and by creeping rhizomes that form extensive clonal colonies. In parts of the San Francisco Estuary, the rate of lateral spread by rhizomes averages between 3.3 and 6.6 feet per year, in contrast with native Pacific cordgrass, which spreads only 0.6 to 2.4 feet per year in the same marshes (Josselyn *et al.* 1993). Similar rates of lateral spread of this species and its hybrids have been recorded more recently in Cogswell Marsh on the Hayward Shoreline (K. Zaremba, M. Taylor, pers. comm.)

The size range of Atlantic smooth cordgrass is wide and highly variable, depending on its local genetics and environment. In nutrient-rich, well-drained marsh sediment, such as along tidal creek banks and on newly colonized tidal flats, extensive dense stands can exceed 10 feet in height. On poorly drained marsh flats, its vegetation is typically sparse and short, but its dense root and rhizome network maintains pure stands and effectively binds marsh sediments. The "tall form" and "short form" of this species were so strikingly different that they were long assumed to be distinct varieties, rather than variations based on local environmental conditions. Modern research indicates that factors related to marsh drainage, such as waterlogged soil chemistry (especially accumulation of toxic soil sulfides), excessive salinity, and nutrient deficiency interact to cause the dramatic differences in growth-forms of Atlantic smooth cordgrass (Bradley and Dunn 1989, Mendelssohn and Seneca 1980, Valiela *et al.* 1978, Smart and Barko 1978). Genetic variations in height forms of Atlantic smooth cordgrass also has been defined in San Francisco Bay (Daehler *et al.* 1999)

In the salt marshes of the Atlantic coastal plain, Atlantic smooth cordgrass is dominant over most of the intertidal zone. Depending on local tidal range, it can grow to and below mean low water (McKee and Patrick 1988), and it can occupy, and even dominate, the marsh plain and the low marsh. Vast, homogeneous stands of Atlantic smooth cordgrass are the characteristic signature of the Atlantic region's tidal marshes (Dame et al. 2000, Adam 1990, Chapman 1964, 1977).

In contrast with Pacific cordgrass, Atlantic smooth cordgrass freely establishes in relatively exposed shorelines with significant wave action, including estuarine sand beaches. It is planted in its native range to stabilize shorelines and to trap and accumulate sediments, and the high density of its tall stems is highly effective at reducing estuarine wave energy (Gleason et al. 1979, Knutson and Woodhouse 1988, Knutson et al. 1990)

In other environmental tolerances, Atlantic smooth cordgrass is also highly resilient. It can survive in salinity over 45 parts per thousand (well above ocean salinity), and grow luxuriantly in dilute brackish water. If buried, it can regenerate from up to about one foot of burial by deposited sediment. Atlantic smooth cordgrass, like other low marsh species, can supply air to its roots in oxygen-poor waterlogged mud, using porous air-filled chambers linking its foliage to roots and rhizomes. Atlantic smooth cordgrass can also tolerate the severe waterlogging and hypersalinity that develops in poorly drained depressions in the salt marsh, including salt marsh pans. Salt marsh pans are frequent and well-developed features of historic San Francisco Estuary marshes, and important habitat for migratory waterbirds (Goals Project 1999). Along the Hayward shoreline of San Francisco Bay, Atlantic smooth cordgrass has colonized many pre-existing pans, converting them to solid cordgrass marsh.

In the San Francisco Estuary, Atlantic smooth cordgrass has displayed many of the ecological traits typical of its performance in its native salt marsh habitat, and some highly novel phenomena as well. Most colonies in the San Francisco Estuary are young, often forming nearly circular, discrete, expanding colonies, which merge into irregular patterns, resembling mold colonies in a petri dish. The edges of the colonies are tall and robust, while the centers often exhibit early symptoms of dieback or "short form" growth habits. The "donut" shape of colonies, in fact, is one of the species' signatures for identification in aerial photographs of San Francisco Bay. This trait is not typical of mature Atlantic salt marshes. In the mild Pacific winters, Atlantic smooth cordgrass shoots tend to retain green leaves and persistent dead leaves through much of the winter. This is an important contrast with native Pacific cordgrass: combined with the invader's much greater stem size and shoot density, year-round dense foliage gives Atlantic smooth cordgrass exceptionally high potential to accumulate and trap estuarine sediment during winter storms or floods.

The San Francisco population of Atlantic smooth cordgrass has generated some unusual growth forms with strikingly atypical appearance. The dwarf form develops a profusion of short lateral shoots instead of a tall main stem, forming pure stands with complete ground cover of dense, low turf-like ankle-high vegetation on the marsh plain. The growth rate of the dwarf form is, however, vigorous. The dwarf form is genetic, not environmentally, induced; it occurs in the same local environments that support luxuriant, tall stands of Atlantic smooth cordgrass, often contiguous with the dwarf patches. It has established at multiple locations in San Francisco Bay (Daehler et al. 1999). A comparable dwarf form of its hybrid daughter species, English cordgrass, independently evolved in Britain and New Zealand (Bascand 1970).

Hybridization of Atlantic smooth cordgrass with native Pacific cordgrass. Perhaps the most novel and significant phenomenon of the San Francisco population of Atlantic smooth cordgrass is the rapid evolution of an aggressively expanding hybrid swarm formed by cross pollination with the native Pacific cordgrass (Daehler and Strong 1997). The hybrid swarm includes first-generation crosses between Atlantic smooth cordgrass and Pacific cordgrass with both species acting as pollen-parents and seed parents. Because the two species' pollination periods overlap little, first-generation crosses are infrequent. Hybrids, however, have a wide range of flowering times, and act as an effective reproductive bridge between the species. The hybrids produce pollen in much greater abundance (21 times greater) and with higher fertility than the native Pacific cordgrass. Superior hybrid pollen production and fertility so overwhelm populations of Pacific cordgrass ("pollen swamping") that native stands of cordgrass produce mostly hybrid back-cross seeds in the presence of flowering hybrid colonies, and fail to reproduce the species sexually (Ayres et al. 1999, Antilla et al. 2000). This process alone, called hybrid assimilation, can result in the extinction of the invaded species (Levin et al. 1996, Rhymer and Simberloff 1996).

Genetic analysis has revealed that numerous large populations of presumed Atlantic smooth cordgrass in the Estuary are predominantly hybrids and back-crosses (introgressants). The ecologically invasive, dominant traits of Atlantic smooth cordgrass appear to be prevalent in the hybrid swarm. "Pure" Atlantic smooth cordgrass is now a minority in most of the rapidly evolving hybrid swarms, and trends suggest that hybrids will eventually replace both parent species, as the hybrid-origin species English cordgrass did in Britain (see English Cordgrass, below). This recently discovered threat of genetic extinction to a native cordgrass from an alien cordgrass invasion is unique to the San Francisco Estuary. No native cordgrasses existed where Atlantic smooth cordgrass invaded Washington and Oregon estuaries, and the cordgrasses native to Europe are genetically isolated from their hybrids.

Atlantic smooth cordgrass, and its hybrids with similar appearance and behavior, are now widely distributed in the Central and South Bay, but they have not yet been detected in the North Bay or Suisun, despite intensive searches. The northern limit of its distribution in 2005 on the east bay is the bay on the western shore of Point Pinole (Giant Marsh), and on the west bay is a clone north of Miller Creek mouth (north of China Camp). The abundance of Atlantic smooth cordgrass and hybrids remains greatest near the point of its original introduction circa 1977 (Pond 3, Hayward Shoreline, Alameda County), and sites of early transplanting (Colma Creek, San Mateo County), early pioneer colonies (Oakland, San Leandro Bay, Hayward Shoreline), and areas of subsequent transplanting (Cogswell Marsh, Hayward). It now is nearly the exclusive marsh plant species of recently formed or restored tidal marshes along the San Leandro-Hayward shoreline, and this trend is expected to increase. Even as the Bay edge salt marshes and levees are eroding landward through wave action, Atlantic smooth cordgrass marsh is spreading in the opposite direction below the wave-cut marsh cliff. Its distribution becomes patchier south of the Dumbarton Bridge, decreasing in size and frequency to Alviso, where it is still relatively rare. It is well established as scattered, large but discrete colonies in the Dumbarton-Mowry Marsh, Newark, mostly in sloughs and disturbed marsh, or recently colonized mudflats. It is a common or dominant feature in marshes from San Bruno, the San Francisco Airport, south to Foster City, and is scattered in variable frequency along the Redwood City shoreline. The Napa-Sonoma and Petaluma Marshes are currently free from the Atlantic smooth cordgrass invasion, but young colonies have recently been detected in Bolinas Lagoon and Drakes Estero on the Point Reyes peninsula (K. Zaremba, pers. comm. 2005).

English Cordgrass (*Spartina anglica*)

English cordgrass is an aggressive invader of mudflats and salt marshes in Britain, New Zealand, Australia, and the Pacific Northwest, and thrives in cool temperate climates. It originated in Britain as a fertile hybrid derived from introduced Atlantic smooth cordgrass and common cordgrass (*S. maritima*), a small, slow-growing creeping cordgrass native to European coasts, now greatly reduced in abundance. Within a century after its origin, English cordgrass became the dominant salt marsh grass in Britain (Lee and Partridge 1983, Gray et al. 1990). It is shorter than Atlantic smooth cordgrass and more grayish in appearance, but partly shares other traits of its parent, such as vigorously spreading rhizomes, ability to transform mudflats into vast stands of low marsh vegetation, and ability to dominate and displace associated plant species. It was introduced to the San Francisco Estuary at Creekside Park, Corte Madera, Marin County, along with Chilean cordgrass, in 1976. Unlike Atlantic smooth cordgrass and Chilean cordgrass, this species failed (so far) to disperse from its point of introduction. It may be at or near its southern climatic limit on the Pacific Coast in San Francisco Estuary.

Chilean Cordgrass (*Spartina densiflora*)

Chilean cordgrass (also called dense-flowered cordgrass) is a distinctive cordgrass species native to South America. It has a bunchgrass growth habit, forming tight clumps or tussocks with short creeping rhizomes, and narrow, firm, in-rolled leaves (Spicher 1984), resembling European beachgrass (*Ammophila arenaria*). It is generally restricted to the middle marsh plain and high marsh zones where pickleweed, saltgrass, jaumea, and other low-growing herbs otherwise prevail. It does not spread into the low marsh where Pacific cordgrass and mudflats naturally dominate the Estuary (Kittleson and Boyd 1997). Chilean cordgrass lacks well-developed tissues specialized for transporting air from foliage to roots (Spicher 1984), a feature common to cordgrasses adapted to low marsh environments.

Chilean cordgrass, along with other South American coastal species, was probably accidentally introduced to Humboldt Bay, California by ship ballast containing seeds from South American ports that traded lumber (Spicher 1984). For most of the 20th Century, Chilean cordgrass was erroneously treated as an "ecotype," or minor geographic variation, of the native Pacific cordgrass, despite the lack of diagnostic traits matching this species. In the late 1970s, the presumed native "Humboldt Bay form" of Pacific cordgrass was deliberately transplanted to salt marsh restoration and landscaping sites at Creekside Park, Corte Madera, Marin County. Within the salt marshes fringing Corte Madera Creek, it has since become a locally dominant component of the middle and high salt marsh vegetation, displacing even robust pickleweed.

A second population of Chilean cordgrass spontaneously established across the Bay from Creekside Park in the ancient marsh plain at Point Pinole (Whittell Marsh), Contra Costa County. The Point Pinole population was discovered in the mid-1990s, and has been largely controlled. A single, large, individual clump of Chilean cordgrass established in a very young restored tidal marsh (breached 1995) at the former Salt Pond 2A, Napa Marsh. That pioneer plant was also eradicated.

Salt-Meadow Cordgrass (*Spartina patens*)

Salt-meadow cordgrass is another rhizome-forming creeping cordgrass of Atlantic salt marshes, but unlike Atlantic smooth cordgrass, it has fine stems with narrow, soft, inrolled leaves, and is intolerant of waterlogged mud. It is naturally confined to the well-drained high salt marsh and relatively moist sandy depressions at or above tidal influence. Two distinctive geographic and ecological types have been recognized, and in the past have been treated as distinct taxonomic varieties. In peaty high salt marshes of the northeastern Atlantic coast, a relatively low form with lax, slender stems forming dense matted turfs with "cowlicks" was once treated as *S. patens* var. *monogyna*. These dense salt marsh turfs are often nearly pure stands of salt-meadow cordgrass crowding out most potentially associated species that occupy gaps in the cover caused by winter ice or drifted wracks. In sandy marshes associated with large barrier beaches and wash-over fans from Cape Cod through the Atlantic coastal plain, a coarser, erect type, formerly recognized as *S. patens* var. *juncea,* is prevalent. Intermediate forms are common.

Between the 1959 publication of *A California Flora* (Munz and Keck 1959) and its 1970 supplement, salt-meadow cordgrass was reported in Southampton Bay, Benicia, Solano County. The time and mode of introduction is unclear. Salt-meadow cordgrass at Southampton occupies large, discrete patches in pure and exceptionally thick stands compared with its native marshes. The patches are distributed close to tidal sloughs, a pattern suggesting local transport by currents. One large stand is spreading into a high marsh site (pickleweed-saltgrass vegetation) that supports a population of an endangered annual plant, soft bird's-beak (*Cordylanthus mollis* ssp. *mollis*). The Southampton Bay cordgrass population appears to match the type description of "variety *monogyna*," the fine-stem type of northeastern Atlantic marshes.

5. CONTROL TOLERANCES

As previously mentioned, the non-native *Spartina* invasion of the San Francisco Estuary is especially threatening to native marsh systems because of hybridization of Atlantic smooth cordgrass and the native Pacific cordgrass. This ability to hybridize, and the current expansion rates of the population of hybrid forms throughout the Estuary, defines the need for a zero tolerance threshold on invasive *Spartina* in San Francisco Bay. The Invasive *Spartina* Project is a regionally coordinated eradication effort that will ultimately be successful only if all infestations are effectively controlled and monitored to eradication.

A single small, expanding clone of hybrid *Spartina* within an otherwise native *S. foliosa* matrix has the capability of ‘swamping’ *S. foliosa* flowers with hybrid pollen, effectively converting the native stand into a hybrid-producing population. Within a couple of growing seasons, the majority of new seedlings establishing in the area will be of hybrid origin, resulting in the eventual extirpation of the native *S. foliosa* from the stand. Repeated throughout the Estuary on various scales, this progression threatens the population stability of native pacific cordgrass stands.

Therefore, where hybrid forms of *Spartina* are identified, efforts must be directed at removing *all* of the plants in the area. There is no acceptable level of hybrid presence in an otherwise native marsh, as the inevitable result of even a small amount of hybrid presence will be the relatively rapid conversion of the marsh to a non-native stand capable of infesting adjacent marshlands.

Spartina densiflora has also been shown to have very rapid expansion rates in the Estuary. In addition, this plant invaded Humboldt Bay, CA to such a degree that approximately 80% of the mudflats and marsh lands have been dominated by it. We are fortunate in the San Francisco Estuary to have only isolated populations of S. densiflora at this point because of the efforts of the ISP and its partners, so as in the case with the more prevalent S. alterniflora hybrids, there is a need for zero tolerance and an excellent opportunity for the eradication of this species before it becomes widespread.

For the other two invasive *Spartina* species in the Estuary, *S. anglica* and *S. patens*, each only inhabits a single infestation site and in a relatively small overall area. However, *S. anglica* is know to be the most invasive species of *Spartina* in the world, itself a fertile hybrid that has dominated introduction sites on several continents. With these types of threats, the fertile environment of the Estuary, and the current size of the infestations, a zero tolerance policy is appropriate. In addition, with a couple effective seasons of treatment, each of these species will be eradicated from the Estuary.

6. DESCRIPTION OF HERBICIDE

Herbicides have proven highly effective in controlling populations of cordgrasses (*Spartina* spp.). The aquatic formulation of imazapyr (Habitat®) was registered for use in the State of California on August 30, 2005. Previously, the *Spartina* Control Program used aquatic glyphosate-based herbicides (Aquamaster® or Rodeo®), which were the only formulations that could be used on a grass species in the Estuary. All ISP partners have switched to imazapyr for the 2007 control season and beyond, although glyphosate will also be used at a single special sub-sites, and may be combined with imazapyr (according to the labels) as a “brown-down indicator” to allow for more rapid detection of missed or skipped areas since imazapyr is such a slow-acting herbicide. Imazapyr will also be used to a very limited degree to “chemically mow” *Spartina* areas to stop seed production but maintain above-ground biomass for endangered California clapper rail protection in sites where phased treatment is required.

There are a number of qualities that make imazapyr the ISP preferred choice over the previous alternative, glyphosate. Glyphosate tends to be strongly adsorbed to sediment and salt particles accumulated on the *Spartina*, rendering the herbicide inactive. It is common for the tides to deposit abundant sediment from the turbid San Francisco Bay onto the invasive *Spartina* in the adjacent salt marshes. Glyphosate also requires significantly longer dry times to fully penetrate the cuticle of the plant and begin translocation. Imazapyr does not have these issues that can reduce its efficacy. In addition, imazapyr is applied at lower concentrations and the applicator does not need to "spray to wet" as with glyphosate, but rather apply the herbicide in a gentle rain to the top 12-18 inches of the plant (its crown). This greatly reduces the amount of herbicide that will enter the environment as a result of the *Spartina* Control Program's efforts, and allows for low volume applications such as aerial helicopter work. This herbicide delivery system is essential to the ISP's initial efforts because of the vast acreage of *Spartina* infesting hazardous and difficult to access marshes.

Both imazapyr and glyphosate must be combined with a suitable surfactant to facilitate uptake and translocation of the herbicide down into the rhizomes. A harmless, inert marker dye or colorant is often added to the tank mix to assist the applicator at achieving full coverage while not over-applying to any areas. The following discussion addresses imazapyr, glyphosate, breakdown products, and typical surfactants and colorants. Detailed descriptions of the chemical properties, degradation rates, environmental fate, and toxicity of imazapyr, glyphosate, and all of the aquatic surfactants evaluated for the *Spartina* Control Program are provided in Appendix 1.

Imazapyr. Habitat® is a solution of 28.7% isopropylamine salt of imazapyr in water, equivalent to 22.6% imazapyr acid equivalents (a.e.) or 2 lbs. acid per gallon, and contains a small amount of an acidifier. Because Habitat® is purportedly the same formulation as Arsenal® and Arsenal® contains acetic acid, the acidifier in Habitat® is likely also acetic acid. (Leson & Associates 2005.) No information has been encountered in the published literature on manufacturing impurities associated with imazapyr. Because virtually no chemical synthesis yields a totally pure product, technical grade imazapyr contains some impurities. However, to some extent, concern for impurities in technical grade imazapyr is reduced by the fact that most existing toxicity studies on imazapyr were conducted with the technical grade product and encompass the toxic potential of the impurities. (SERA 2004.) A generic version of this aquatic imazapyr formulation is now available from NuFarm under the product name Polaris AQ™. Some ISP partners may choose to switch to this generic product in 2007. According to the Polaris AQ™ label, it contains the identical percentage of imazapyr as Habitat®, and does not have any additional restrictions for its use.

Imazapyr inhibits an enzyme in the biosynthesis of the three branched-chain aliphatic amino acids valine, leucine, and isoleucine. Because animals do not synthesize branched-chained aliphatic amino acids but obtain them from eating plants and other animals, the engineered mechanism for plant toxicity, *i.e.* the interruption of protein synthesis due to a deficiency of the amino acids valine, leucine, and isoleucine, is not generally relevant to birds, mammals, fish or invertebrates. Any toxicity to these receptors occurs through different mechanisms. (Entrix 2003.) Imazapyr is relatively slow acting taking several weeks for the plants to show effects. However, plants cease growth within 24 hours of a successful application (J. Smith, pers. comm. 2006). On *Spartina*, it takes 2-4 weeks after treatment to see visible effects such as yellowing of the leaves, and complete plant death can take several months. In the San Francisco Estuary, with the relatively late season applications on invasive *Spartina* (mainly because of endangered species issues), the treated plants may not reveal much of a response before natural senescence, but will simply not emerge in the spring of the following year if fully impacted.

Glyphosate. Aquamaster® and Rodeo® are aqueous solutions containing 53.8% glyphosate in its isopropylamine salt form or 4 lbs. acid per gallon, and contain no inert ingredients other than water. The primary decomposition product of glyphosate is aminomethylphosphonic acid (AMPA), and the commercial product contains an impurity, 2,4-nitrosoglyphosate (NNG). The potential effects of AMPA and NNG are encompassed by the available toxicity data on glyphosate and glyphosate formulations (SERA 1996).

Glyphosate inhibits an enzyme needed to synthesize an intermediate product in the biosynthesis of the aromatic amino acids, essential for protein synthesis and to produce many secondary plant products such as growth promoters, growth inhibitors, phenolics, and lignin. Animals do not synthesize these aromatic amino acids and glyphosate therefore has low toxicity to these receptors. (Schuette 1998.) In general, glyphosate herbicides are somewhat faster acting than imazapyr herbicides. On *Spartina*, complete brown-down occurs within 7 to 21 days. (K. Patten, pers. comm. 2004).

Surfactants. For most foliar applications of aquatic herbicide formulations, adjuvants must be added to spray solutions to improve the performance and minimize variation of herbicide efficacy. Surfactants are designed to improve the spreading, dispersing/emulsifying, sticking, absorbing, and/or pest-penetrating properties of the spray mixture. (Tu *et al.* 2001.) The pure herbicide formulation mixed with water will stand as a droplet on the waxy leaf surface and the small area of contact therefore provides little potential for uptake of the active ingredient into the foliage. Water droplets containing a surfactant will spread in a thin layer over a waxy leaf surface and improve herbicide uptake by improving herbicide distribution on the leaf surface. As mentioned above, both Habitat® and Polaris AQ™, as well as the glyphosate herbicides Aquamaster® and Rodeo® require the addition of surfactants for post-emergent applications such as the control of invasive *Spartina*.

Imazapyr. The Habitat® specimen label recommends a variety of different spray adjuvants for use on post-emergent vegetation. For non-ionic surfactants the label recommends a rate of 0.25% v/v or higher, preferably of a surfactant with a hydrophilic to lipophilic ratio between 12 and 17 and with at least 70% surfactant in the formulated product. (BASF 2003.) Alternately, the label recommends the use of methylated seed oils or vegetable oil concentrates at the rate of 1.5 to 2 pints per acre. For spray volumes greater than 30 gallons per acre, the surfactant should be mixed at a rate of 1%. The label further indicates that these oils may aid in Habitat® deposition and uptake by the plants under moisture or temperature stress. Silicone-based surfactants, which may reduce the surface tension of the spray droplet, allowing greater spreading on the leaf surface as compared to conventional non-ionic surfactants, are also recommended. However, the manufacturer points out that some silicone-based surfactants may dry too quickly, limiting herbicide uptake. (BASF 2004.)

One study from Washington State concluded that the esterified seed oil surfactant tested, Competitor®, performed better than the other surfactants tested, *i.e.* Agri-Dex®, a crop oil-based surfactant, and R-11®, a non-ionic surfactant. This finding is supported by other studies. (Patten 2002.) The author recommended using a methylated seed oil surfactant for aerial applications and for unfavorable conditions such as less than 6 hours of drying time or moist leaves. The experience of the ISP from 2005 & 2006 has shown that a lecithin product, Liberate®, has also been highly effective with imazapyr. In addition, this product acts as a drift retardant which may help in helicopter treatments as well as other broadcast applications to ensure full coverage on the target *Spartina* and minimize drift onto non-target marsh plants.

Glyphosate. The Aquamaster® and Rodeo® specimen labels recommend the use of a non-ionic surfactant containing at least 50% active ingredient at a rate of 2 or more quarts per 100 gallons of tank mix (0.5% v/v). With glyphosate it is also important to balance the pH of the tank water to ensure effectiveness, and some adjuvants are designed with this purpose in mind, namely LI-700®.

Not all surfactants provide the same effectiveness and surfactant costs vary widely. In general, non-ionic surfactants and crop oil concentrates are the least expensive of the surfactant classes, followed by esterified seed oils and organo-silicates. (Miller & Westra 2004.) The ISP identified a number of potential surfactants for use with Habitat®, Aquamaster® or Rodeo®. They include the non-ionic surfactants LI-700®and Liberate®; the crop-oil concentrate Agri-Dex®; the esterified seed oil Competitor®; and the organo-silicones Dyne-Amic® and Kinetic®. Based on the anticipated efficacy of the products and their superior relative toxicities, the ISP expects to use Competitor®, Liberate®, and Agri-Dex®, in the *Spartina* Control Program, and LI-700® may be used in the few cases where glyphosate is employed due to its ability to balance the pH of the tank. If actual efficacies of these products prove to be inadequate, the ISP will then consider Dyne-Amic® and Kinetic®. Cygnet Plus® was evaluated and originally included in the list of surfactant choices for 2005, but it was shown to be ineffective with imazapyr and has been removed from the list available to the ISP partners. It is known that many surfactants adsorb to soil particles, but the long-term fates of most adjuvants in the environment are largely unknown. (Tu *et al.* 2001.)

<u>Agri-Dex</u> (Helena Chemical Company) is a non-ionic surfactant consisting of a paraffin base petroleum oil, polyol fatty acid esters, and polyethoxylated derivatives of the fatty acid esters. Toxicity studies classified this surfactant as a toxicity category of 3-4 (CAUTION).[3]. Biodegradation of this adjuvant is presumed to be rapid.

<u>Competitor</u> (Wilbur-Ellis Company) is a modified vegetable oil containing a non-ionic emulsifier system. The ingredients include ethyl oleate, sorbitan alkyl polyethoxylate ester, and dialkyl polyoxy-ethylene glycol. Toxicity studies classified this surfactant as a toxicity category of 3-4 (CAUTION).

<u>Dyne-Amic</u> (Helena Chemical Company) is a proprietary blend of non-ionic organosilicone surfactants and a methylated vegetable oil. Toxicity studies classified this surfactant as a toxicity category of 3-4 (CAUTION).

<u>Kinetic</u> (Helena Chemical Company) is a non-ionic wetting agent that allows for the rapid spreading and absorption of herbicide sprays into the target vegetation, and is espe-

3 Toxicity categories are determined by the U.S. EPA for human health affects. See http://www.epa.gov/oppfead1/labeling/lrm/chap-08.htm for more information on pesticide label requirements.

cially effective with water-based herbicide formulations. Its active ingredients include organosilicone and polyoxypropylene-polyoxyethylene copolymer. Toxicity studies classified this surfactant as a toxicity category of 3-4 (CAUTION).

Liberate (Loveland Industries, Inc.) is a non-ionic, low foam penetrating adjuvant. Its active ingredients are lecithin (phosphatidylcholine, which is a naturally occurring lipid that biodegrades readily), methyl esters of fatty acids, and alcohol ethoxylate. In a 1 % solution, the pH is an almost neutral 6.8. Toxicity studies classified this surfactant as a toxicity category of 3-4 (CAUTION). It improves deposition and retards drift by producing a more uniform spray pattern.

LI-700 (Loveland Industries, Inc.) contains phosphatidylcholine (lecithin), which is a naturally occurring lipid that biodegrades readily. It also contains methylacetic acid and alkyl polyoxyethylene ether. Toxicity studies classified this surfactant as a toxicity category of 1 (DANGER) because of corrosive properties to the skin and/or eyes. Biodegradation of this adjuvant is presumed to be rapid because of the natural lecithin ingredients.

Colorant. There are several colorants suitable for use in the marsh environment, all of which are similar in composition and performance. Blazon Spray Pattern Indicator (Milliken Chemical), a typical colorant, is a water-soluble polymeric product. As with most colorant products, the active ingredients in Blazon are proprietary; the Material Safety Data Sheet indicates that it is non-hazardous and non-toxic. The product information sheet reports that the product is non-staining to the skin or clothing. A literature survey on the toxicity of color indicators done for the U.S. Department of Agriculture reports "most commercial indicators are blue … and most often a form of Acid Blue 9…" (McClintock 1997 and Zullig 1997 cited in SERA 1997b). Acid Blue 9 is a disodium salt classed chemically as a triphenelmethane color (SERA 1997b). The Cosmetic, Toiletry, and Fragrance Association (CTFA) name for certified batches of Acid Blue 9 is FD&C blue No. 1.

Herbicide application. Impacts to water quality from herbicide application depend on environmental fate, degradation rates of active agents and decomposition products of the herbicides. The primary route by which herbicide solution may contact water is by overspray directly onto the water surface, or by washing off from plants due to precipitation or tidal inundation.

Imazapyr and glyphosate solutions will be applied as sprays to plant foliage for control of invasive *Spartina*. Spray mixtures may be administered from manually transported tanks (backpack sprayers) or spray equipment mounted on trucks, amphibious tracked vehicles, boats, or helicopters. Application rates will be consistent with the product labels (Table 4).

Applications from backpack sprayers or conventional spray truck would entail workers walking through the marsh and applying herbicide directly to target plants, with limited overspray to surrounding plants or water surfaces. Spot application from amphibious tracked vehicles or boats would entail vehicles moving through the marsh or adjacent waterway applying herbicide with hand-held equipment to target vegetation with limited overspray. Aerial application would be by helicopter with either a boom sprayer (a horizontal pipe with spray nozzles along its length, mounted to the bottom of the helicopter) or a spray ball (a hollow ball with nozzles suspended from the bottom of the helicopter). Broadcast aerial application involving a boom sprayer would result in a wider dispersion of herbicides, with greater potential for overspray onto non-target areas or the water surface. Aerial application will be used primarily at large areas of dense cordgrass infestations, particularly in locations where little native cordgrass and other non-target plants are nearby.

Environmental Fate of Herbicides

Herbicide mixtures may be indirectly discharged to surface waters by tidal action or rainfall that rinses the herbicide solution from the plants. Rainfall is unlikely to occur during the planned application season (late summer in the San Francisco Bay region), and herbicide applications would be postponed if rainfall were predicted, but tidal inundation is inevitable in many locations on a regular cycle. Applications to invasive *Spartina* along slough or creek banks or at the Bayfront on fringe marshes and mudflats will result in a small percentage of the herbicide directly entering the water column.

Food-web exposures become significant only with chemicals that have a tendency to bioaccumulate or biomagnify. The adverse effects associated with bioaccumulative chemicals relate to their propensity to transfer through the food web and accumulate preferentially in adipose or organ tissue. Basic routes for organism exposure to bioaccumulative compounds are the transport of dissolved contaminants in water across biological membranes, and ingestion of contaminated food or sediment particles with subsequent transport across the gut. For upper-trophic-level species, ingestion of contaminated prey is the predominant route of exposure, especially for hydrophobic chemicals.

U.S. EPA's Hazardous Waste Identification Rule (USEPA 1999) identifies compounds that are recognized as having a low, medium or high potential for bioaccumulation. For bioaccumulation in aquatic systems, rankings were determined using bioaccumulation factors in fish, which are indicated in laboratory tests as having low octanol-water partitioning coefficient (or log K_{ow})) values for organic compounds. Bioaccumulation potential is defined as follows:

Bioaccumulation potential	*Bioaccumulation Factor (BAF)*	*log K_{ow}*
High	BAF >= 10,000	log K_{ow} >= 4.0
Medium	10,000 > BAF >= 100	4.0 > log K_{ow} >= 2.0
Low	BAF < 100	log K_{ow} < 2.0

Imazapyr. Under typical environmental conditions of pH 5-9, imazapyr is ionized and therefore highly soluble in water. Because of its high solubility, imazapyr has an inherently low sorption potential with a low soil organic carbon sorption coefficient (K_{oc}) of 8.81 (log K_{oc}), suggesting very high mobility in soil and little adsorption to suspended solids and sediment. Its octanol/water partition coefficient (K_{ow}) has been reported at 0.22 (log K_{ow}), reflecting its high solubility in water and low solubility in lipids, and hence low propensity to bioconcentrate. A low bioconcentration factor (BCF) of 3 was calculated for imazapyr, which suggests a low potential for bioconcentration in aquatic organisms. (Leson & Associates 2005.)

Imazapyr is relatively mobile in soils because it adsorbs to soils and sediments only weakly. Adsorption increases with decreasing pH. Above a pH of 5, imazapyr is ionized and does not adsorb to soil. Aerobic degradation in soils occurs primarily by very slow microbial metabolism with quinoline as the main metabolite. (Entrix 2003.)

Table 4a: Imazapyr herbicide mixture component concentrations and application rates for treatment of non-native *Spartina* in San Francisco Estuary (Leson & Associates 2005.)

Application Method	Spray Volume	Formulation	Active Ingredient[1]	Surfactant[2]	Colorant
High volume hand-held sprayer	100 gal/acre	0.52-0.75% solution 4-6 pints/100 gal	1-1.5 lb a.e./acre	0.25% v/v NIS with ≥70% a.i.; ~1% v/v MSO, ESO, or VOC; SBS according to label	3 qt/100 gal
Low-volume directed sprayer	20 gal/acre	0.75-1.5% solution 1.2-2.4 pints/20 gal	0.3-0.6 lb a.e./acre	0.25% v/v NIS with ≥70% a.i.; ~1% v/v MSO, ESO, or VOC; SBS according to label	3 qt/100 gal
Broadcast sprayer/ Aerial application	10-30 gal/acre	2.5-7.5% solution 6 pints/10-30 gal	0.5-1.5 lb a.e./acre	0.25% v/v NIS with ≥70% a.i.; ~1% v/v MSO, ESO, or VOC; SBS according to label	0.5-1.5 qt/acre

[1] Active ingredient in Habitat® is imazapyr isopropylamine salt; values expressed as imazapyr acid equivalent
[2] NIS = non-ionic surfactant; MSO = methylated seed oil; ESO = esterified seed oil; VOC = vegetable oil concentrate, SBS = silicone-based surfactant, %v/v = percentage based on volume by volume

Table 4b: Glyphosate herbicide mixture component concentrations and application rates for treatment of non-native *Spartina* in San Francisco Estuary (Leson & Associates 2005.)

Application Method	Spray Volume	Formulation	Active Ingredient[1]	Surfactant[2]*	Colorant
High volume hand-held sprayer	100 gal/acre	1-2% solution 1-2 gal/100 gal	4-8 lb a.e./acre	≥0.5% v/v NIS with ≥50% a.i.	3 qt/100 gal
Low-volume directed sprayer	25-200 gal/acre	1-8% solution 1-8 gal/100 gal	1.35-10.8 lbs a.e./acre	≥0.5% v/v NIS with ≥50% a.i.	3 qt/100 gal
Broadcast sprayer/ Aerial application	7-40 gal/acre/ 7-20 gal/acre	4.5-7.5 pints/acre	2.25-3.75 lb a.e./acre	≥0.5% v/v NIS with ≥50% a.i.	0.5-1.5 qt/acre

[1] The active ingredient in Rodeo® and Aquamaster® is glyphosate isopropylamine salt; values are expressed as glyphosate acid equivalent
[2] NIS = non-ionic surfactant, %v/v = percentage based on volume by volume

Conditions in sediments differ substantially from those in soils, both in terms of the regular exchange of waters within the sediment pore water and over it, and in the degree of oxygenation in sediments that affect microbial metabolism. Because the pH of sediment surfaces and sediment pore water in intertidal mudflats is above neutral (pH >7), imazapyr will be entirely in its ionized form. Thus, adsorption to sediments is expected to be minimal. (Entrix 2003.) Microbial metabolism in sediments has been determined to be insignificant. One study determined the half-life of imazapyr in the pore water of aerobic sediment at 17 months.

The degradation of imazapyr when applied directly to water largely mimics the pathway by which the herbicide would be mobilized at high tide after application to *Spartina* during low tide. Residual imazapyr on the plants that have not completely dried or did not get absorbed by the plants will be inundated by the incoming tide and presumably solubilized. Aquatic degradation studies under laboratory conditions demonstrated rapid initial photolysis of imazapyr with reported half-lives ranging from 3 to 5 days. (SERA 2004.) The two primary photodegradation products were rapidly degraded with half-lives less than or equal to 3 days and eventual mineralization to carbon dioxide. (Entrix 2003.)

Degradation rates in turbid and sediment-laden waters, common to estuarine environments, are expected to be lower than those determined under laboratory conditions. In controlled field dissipation studies in two freshwater pond systems with application of 1.5 lb imazapyr a.e./acre, imazapyr rapidly dissipated from the water with first-order half-lives of 1.9 days and 12.8 days. No detectable residues of imazapyr were found in the water and sediment after 14 and 59 days, respectively. (Entrix 2003.) The ISP's NPDES water quality monitoring at treatment sites in 2005 did not detect imazapyr in the adjacent surface water one-week post-treatment at any of the sites where samples were taken.

In estuarine systems, dilution of imazapyr in the incoming tide will contribute to its rapid dissipation and removal from the area where it has been applied. Studies in estuaries in Washington State examined the fate of imazapyr applied at a standard rate of 1.5 lb imazapyr a.e./acre directly to sediment. The study design was conservative because imazapyr was applied to bare mudflats with no algal or emergent vegetation intercepting the herbicide. The study measured immediate maximum concentrations of imazapyr in intertidal waters and sediment less than 3 hours after application and short-term concentrations between 24 and 72 hours after application. Sediment samples collected 3 hours after application were retrieved immediately after the first tidal wash over the area. Maximum concentrations in water and sediment were detected at 3.4 mg/L and 5.4 mg/kg, respectively. Measurable concentrations of imazapyr declined exponentially in both water and sediment, approaching the zero-asymptote at 40 and 400 hours with half-lives of <0.5 and 1.6 days, respectively. Water collected 20 and 200 feet outside the spray zone with the first incoming tide was 99% lower than the maximum water concentration at the edge of the spray zone. (Leson & Associates 2005.) Application of the same amount of herbicide to a stand of 5.5-foot tall *Spartina* resulted in a 75% reduction in concentrations in sediment through interception by the canopy. (Patten 2003.) In sum, this research suggests that imazapyr quickly dissipates in estuarine environments. In addition, the same researcher observed that other vegetation immediately colonizes the plots treated with imazapyr after the *Spartina* plants have died, which supports the conclusion of very low persistence of imazapyr in estuarine environments.

Glyphosate. Under typical environmental conditions of pH 5-9, glyphosate is ionized. Glyphosate and its salts are readily soluble in water with a solubility of about 12,000 mg/L. Its interactions with soil and sediment are primarily ionic, rather than hydrophobic and pH dependent. Laboratory and field studies indicate that glyphosate is strongly and reversibly adsorbed by soil, sediment, and suspended sediment. Glyphosate is inactivated through soil adsorption. Because glyphosate adheres strongly to particles, it does not readily leach to waters (Sprankle *et al.*, 1977 cited in Albertson, 1998), and potential movement of glyphosate to groundwater is unlikely. Due to its negligible vapor pressure (7.5×10^{-8} mmHg) and its ionic state in water, glyphosate is not expected to volatilize from water or soil. Glyphosate's K_{ow} has been reported at 0.00033, indicating its high solubility in water, low solubility in lipids, and thus low potential to bioconcentrate.

All reported bioaccumulation factor values for glyphosate in aquatic organisms are well below 100 (Ebasco 1993; Heyden 1991; Wang *et al.* 1994). The highest bioaccumulation factor of 65.5 was reported for tilapia (a species of fish) in fresh water (Wang *et al.* 1994). Other studies report much lower bioaccumulation factors in the range of 0.03 to 1.6 for fish (Ebasco 1993). Most studies report rapid elimination and depuration from aquatic organisms after exposure stops (Ebasco 1993). Therefore, bioaccumulation of glyphosate is considered to be low and food-web transfer is not considered to be a significant exposure route.

Soil studies have determined glyphosate half-lives ranging from 3 to 130 days. The soil field dissipation half-life averaged 44 to 60 days. (Leson & Associates 2005.) In the soil environment, glyphosate is resistant to chemical degradation, is stable to sunlight, is relatively non-leachable, and has a low tendency to runoff (except as adsorbed to colloidal matter). It is relatively immobile in most soil environments as a result of its strong adsorption to soil particles. Glyphosate is rapidly and strongly adsorbed to sediment, which appears to be the major sink for glyphosate in aquatic systems. Like in soils, the herbicide is inactivated and biodegraded by microorganisms.

Several studies indicate that glyphosate is stable in water at pH ranging from 3 to 6. The photolytic half-life of glyphosate in deionized water exposed outdoors to sunlight was approximately 5 weeks at 100 ppm and 3 weeks at 2000 ppm. Glyphosate shows little propensity toward hydrolytic decomposition. Its hydrolysis half-life is greater than 35 days. It is also stable to photodegradation under visible light but photolyzes when exposed to UV radiation. Glyphosate's loss from water occurs mainly through sediment adsorption and microbial degradation. The rate of microbial degradation in water is generally slower because there are fewer microorganisms in water than in most soils. Studies conducted in a forest ecosystem found that glyphosate dissipated rapidly from surface water ponds high in suspended sediment, with first order half-lives ranging from 1.5 to 11.2 days. In streams, residues were undetectable within 3 to 14 days. Other studies using water from natural sources determined glyphosate's half-life ranging from 35 to 63 days. (Leson & Associates 2005.) For all aquatic systems, sediment appears to be the major sink for glyphosate residue. A review of the literature on glyphosate dissipation applied under estuarine conditions suggests that 24 to 48 hours after applications, glyphosate concentrations in water were reduced by more than 60-fold.

Energetic tidal cycles and tidal currents effectively disperse bound (adsorbed) glyphosate and surfactants and dilute them in microbially active suspended sediment. Studies of the fate of glyphosate and surfactants applied in tidal marshes and mudflats have reported that concentrations of both substances dropped below detection levels as soon as two tidal cycles (one day) to seven days (Kroll 1991, Paveglio *et al.* 1996) after application. The initial tidal submergence of sprayed surfaces disperses a large fraction of applied glyphosate and surfactant.

Research conducted for the California Department of Food and Agriculture (Trumbo 2002) studied the environmental fate and aquatic toxicity of Rodeo and R-11 in three locations, including a Sacramento-San Joaquin Delta slough, a riverine area, and a no-outlet pond. This study measured glyphosate, aminomethylphosphonic acid (AMPA; glyphosate's primary metabolite), nonylphenol ethoxylate, and nonylphenol at treated sites one hour, two days, and eight days after application. The study also tested for toxicity using 96-hour toxicity tests with the fish species fathead minnow *Pimephales promelas*. The study found that concentrations of the tested constituents at slough and river sites (with moving water) was below detectible levels for all tests, and that there was no significant mortality of test fishes. The pond site, however, showed detectable residues of glyphosate, nonylphenol ethoxylate, and nonylphenol at one hour and two days after treatment, but all constituents were below detection limits by day eight. The one-hour pond samples experienced 30% mortality of test fishes, which, because of the relatively low concentrations of glyphosate (which is known to be non-toxic at the detected level), was attributed to effects caused by nonylphenol ethoxylate and nonylphenol. The two- and eight-day tests showed no significant mortality to test fishes.

Patten (2002) compiled data on the fate of glyphosate in water and sediment following applications in estuarine environments. Data are presented as geometric means for immediate maximum concentration (<3hrs after application) and short-term concentration (between 24 hrs and 48 hrs after application). For use rates between 8 and 16 kg/ha (7-15 lbs/acre), the immediate maximum geometric mean glyphosate concentrations were 0.174 mg/L (174 μg/L) in water and 2 mg/kg in sediment. The short-term geometric mean glyphosate concentrations were 0.003 mg/L (3 μg/L) in water and 1.9 mg/kg in sediment.

These independent lines of research in the fate of imazapyr or glyphosate combined with a surfactant in tidal (and other) habitats suggest that potential impacts to water quality and beneficial uses of waters of the State caused by spraying these herbicide mixtures in intertidal environments are likely be small and temporary. Therefore, controlled applications (i.e., following label instructions) of registered herbicides are not expected to degrade water quality, except for limited temporal and spatial extent.

In summary, the use of imazapyr or glyphosate combined with a surfactant to treat infestations of non-native cordgrass would result in less than significant impacts on water quality due to the rapid degradation rate and controlled application of herbicides only on target plants. Since application of herbicides would take place during low tide and low wind conditions, the herbicide would likely be absorbed by plants for a minimum of several hours (up to several weeks in high marsh) following application resulting in less than significant quantities of imazapyr, glyphosate or surfactants entering the water.

Potential Biological and Ecological Effects

The known properties of the herbicides, potential methods of application, and the ecological characteristics of the Estuary were evaluated to develop a conceptual model (Figure 2) and identify likely receptors and exposure pathways. This model includes identifi-

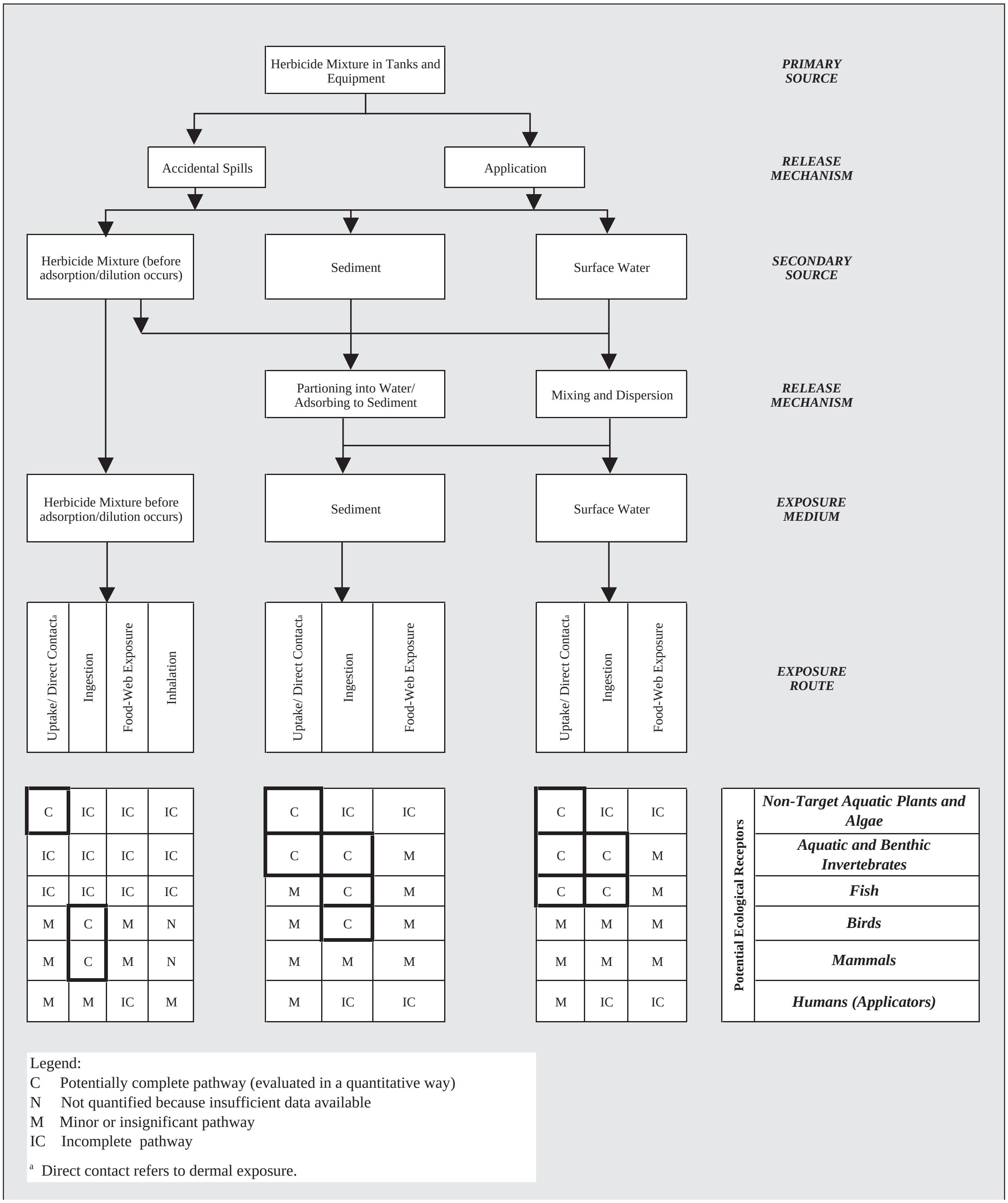

Figure 2. Conceptual Model of Possible Exposure of Biological Organisms to Herbicide Mixture Used by the *Spartina* Control Program

cation of primary and secondary herbicide sources, release mechanisms, exposure media, exposure routes, and potential ecological receptors.

For effects to occur, a receptor and a complete exposure pathway must be present. An exposure pathway is only considered complete when all four of the following elements are present: project- related source of a chemical, a mechanism of release of the chemical from the source to the environment, a mechanism of transport of the chemical to the ecological receptor, and a route by which the receptor is exposed to the chemical.

The exposure routes associated with the complete pathways include direct contact with the herbicide mixture during and immediately after application, ingestion of contaminated surface water and sediments, direct contact with contaminated surface water and sediments, and food-web exposure. The conceptual model (Figure 2) illustrates the links between sources, release and transport mechanisms, affected media, exposure routes, and potentially exposed ecological receptors. Although several complete exposure pathways may exist, not all pathways are comparable in magnitude or significance. The significance of a pathway as a mode of exposure depends on the identity and nature of the chemicals involved and the magnitude of the likely exposure dose. For birds and mammals, ingestion is generally the most significant exposure pathway. Dermal contact is expected to be insignificant and unquantifiable due to the nature of the site and frequent movement, ranging habits, and furry or feathery outer skin of most wildlife species.

Because Project applications of herbicides would occur only once or (at most) twice a year, and compounds in the herbicide mixture are not expected to persist in significant concentrations for more than several hours, chronic exposure is not likely. In addition, since imazapyr is a newly registered herbicide in California as of 2005, there are few other sources for its introduction to the environment to add to those of the ISP. Therefore, this evaluation focuses on acute toxicity, which would occur when the compounds are present at relatively high concentrations during and immediately following application.

Herbicide solutions have the potential to affect organisms that live in the water column, including algae, non-target plants, fish and aquatic invertebrates. While some other receptors such as mammals and birds may spend a considerable portion of their time in the water, they are generally more likely to be affected by other exposure routes, primarily dermal contact during application and incidental ingestion of contaminated sediment during foraging.

Non-Target Aquatic Plants and Algae

Due to their engineered mechanisms of action, imazapyr and glyphosate are toxic to a wide variety of plants. Native salt marsh plants, aquatic macrophytes, and algae in the Estuary waters where the herbicides would be applied could be negatively affected. However, both imazapyr and glyphosate are ineffective for treating submerged aquatic vegetation.

Imazapyr. The species most sensitive to technical grade imazapyr and an herbicide/surfactant mixture appear to be aquatic macrophytes with reported EC_{25} values for duckweed (*Lemna gibba*) of 0.013 mg/L for growth and for common water milfoil (*Myriophyllum sibiricum*) of 0.013 mg/L for shoot growth and 0.0079 mg/L for root growth. (Hughes 1987; Roshon *et al.* 1999; both in SERA 2004.) Aquatic algae appear to be substantially less sensitive. The most sensitive species of algae tested was a unicellular green algae (*Chlorella emersonii*) with an EC_{50} of about 0.2 mg/L for growth. Some algal species appear to be stimulated rather than inhibited by imazapyr concentrations of up to 100 mg/L. (Hughes 1987 in SERA 2004.) Some species of plants, including aquatic plants, may develop resistance to imazapyr. Bioassays conducted on *Chlorella emersonii* indicated that resistant strains may be less sensitive by a factor of 10. (Landstein *et al.*

1993 in SERA 2004.) Due to the infrequent application of imazapyr for control of *Spartina*, *i.e.* once per year, development of resistance to imazapyr is unlikely.

Recent studies conducted in Washington State also document the potential for imazapyr to impact non-target vegetation. Effects of imazapyr application on non-native Japanese eelgrass were compared to glyphosate application. For both herbicides, the eelgrass canopy was killed if herbicide was applied on dry eelgrass at low tide with imazapyr being more toxic. Application onto an eelgrass bed with a thin overlying film of water did not result in toxic effects. Within 12 months, all treated eelgrass beds had recovered. Persistence was not recorded in the sediment underlying these eelgrass beds. (Patten 2003.)

Glyphosate. In laboratory growth inhibition studies with submerged aquatic plants no adverse effects on the growth of elodea (*Elodea canadensis*), water milfoil (*Myriophyllum spicatum*), and wild celery (*Valisneria americana*) were found with glyphosate concentrations of up to 1 mg/L. (Forney & David 1981 in WS FEIS 1993.) These results are consistent with the findings of other investigators who report that submerged plants are either resistant or affected only by very high glyphosate concentrations. (Evans 1978; Peverly & Crawford 1975; both in WS FEIS 1993.) A large number of studies with a variety of green algae, blue-green algae, diatoms, and periphyton indicate that glyphosate is slightly toxic to practically non-toxic to most algae. Most algae tolerate concentrations of glyphosate greater than 1 mg/L. (WS FEIS 1993.) Species of algae vary in their sensitivity to glyphosate in terms of population growth (EXTOXNET, Giesy 2000). Field studies indicate the least toxicity to phytoplankton (microscopic floating algae), possibly because of dilution and adsorption in open water and flooded marshes.

Few data are available on effects to marine algae, as most toxicity tests have been performed on freshwater species. Giesy *et al.* (2000) reviewed the data available on glyphosate toxicity to micro-organisms, and found that acute toxicity EC_{50} values ranged from 2.1 to 189 mg/L. NOECs ranged from 0.73 to 33.6 mg/L. Giesy *et al.* (2000) also reviewed the data available on glyphosate toxicity to aquatic macrophytes, and found that acute toxicity EC50 values ranged from 3.9 to 15.1 mg/L.

It should be noted that these studies included tests on the (non-aquatic) Roundup formulation as well as other forms of glyphosate. The formulated product known as Roundup, which includes the terrestrial surfactant polyethoxylated tallowamine (POEA) is known to be more toxic than the technical grade glyphosate found in aquatic formulations such as Aquamaster. For studies conducted on microorganisms using glyphosate tested as isopropylamine salt, EC_{50} values ranged from 72.9 to 412 mg/L, and NOEC values ranged from 7.9 to 26.5 mg/L (Giesy *et al.* 2000). The lowest of these NOEC values (0.73 mg/L) is well above the maximum concentration of 0.026 mg/L reported by Paveglio *et al.* (1996) and the immediate maximum geometric mean glyphosate concentration of 0.174 mg/L reported by Patten (2002). Therefore, these data indicate that impacts to non-target submerged aquatic plants or algae are not likely. Impacts in estuarine conditions with high concentrations of suspended sediment, which interfere with glyphosate activity, would be even less likely.

Aquatic and Benthic Invertebrates

Imazapyr. Imazapyr has been found to have low toxicity to aquatic invertebrates. A study where *Daphnia* was exposed to an imazapyr formulation (~50%) produced a 48-hour EC_{50} concentration of 373 mg imazapyr a.e./L (Cyanamid 1997 in Entrix 2003.). Another study with Arsenal® (identical to Habitat®) with an unspecified surfactant determined a 48-hour LC_{50} of 350 mg Arsenal/L (79.1 mg imazapyr a.e./L) and a NOEC of 180 mg Arsenal/L (40.7 mg imazapyr a.e./L) for the freshwater flea (*Daphnia magna*), highlighting the potential effects of surfactants on aquatic toxicity. Other studies also reported 24 and 48-hour LC_{50} concentrations of greater than 100 mg/L, the highest dose tested ("HDT"), in static tests conducted with newly-hatched *Daphnia.* (Kintner & Forbis 1983 in SERA 2004.) Chronic studies reported no adverse effects on survival, reproduction or growth of 1st generation *Daphnia* after 7, 14 and 21-days of exposure at concentrations up to 97.1 mg/L, the HDT. (Manning 1989 in SERA 2004.). Testing with other invertebrate species that exhibit alternative life cycles has been limited to survival of pink shrimp (*Penaeus duorarum*) and growth studies with the Eastern oyster (*Crassostrea virginica*). Acute toxicity to pink shrimp was determined at LC_{50} >132 mg imazapyr a.e. /L, the HDT, which was also the NOEC. The EC_{50} for growth inhibition of the Eastern oyster was established at a concentration greater than 132 mg imazapyr a.e./L, with the NOEC set at this concentration, the HDT. (Mangels & Ritter 2000 in SERA 2004.)

A recent microcosm study analyzing benthic macroinvertebrates in a logged pond confirmed the low toxicity of imazapyr to benthic freshwater macroinvertebrates. The study analyzed macroinvertebrate community composition, chironomid deformity rate, and chironomid biomass and concluded that imazapyr did not affect the macroinvertebrate community at the concentrations tested. The NOEC was determined to be greater than 18.4 mg/L (Fowlkes et al. 2003.)

***Glyphosate*.** Glyphosate is only slightly toxic to practically non-toxic to marine and freshwater aquatic invertebrates. Acute toxicity for freshwater invertebrates varies from 545 to 780 mg/L for water flea (*Daphnia magna*), to 673 mg/L for mosquito 4th instar (*Anopheles quadrimaculatus*), to 1,157 mg/L for a leech (*Nephaelopsis obscura*). Acute toxicity for marine invertebrates was reported as greater than 10 mg/L for Atlantic oyster larvae (*Crassostrea virginica*), 281 mg/L for grass shrimp (*Palaemonetes vulgaris*), and 934 mg/L for fiddler crab (*Uca pugilator*). (ExToxNet 2005; Henry 1992, Heydens 1991; both in SERA 2004.) The wide variation in the aquatic toxicity of glyphosate has been attributed to the dilution water, temperature, formulation, and the amount of suspended sediment in the water. Toxicity appears to increase with temperature, and decrease with elevated pH and suspended sediment. (Schuette 1998).

Giesy *et al.* (2000) reviewed the data available on glyphosate toxicity to aquatic invertebrates. Few data were available for marine species, and those studies that did use marine species were conducted with glyphosate acid, not salt. Acute toxicity EC_{50} values for five marine species ranged from 281 mg/L to greater than 1000 mg/L, and NOEC values ranged from 10 to 1000 mg/L. Data compiled by Ebasco (1993) include mortality tests on two marine species, for which EC_{50} values were found to be 281 mg/L and greater than 1,000 mg/L.

Grue *et al.* (2002) conducted laboratory studies to evaluate reproductive effects of exposure to Rodeo mixed with four different surfactants, including R-11, LI 700, and Agri-dex, on Pacific oysters. The EC_{50} for glyphosate alone was 68.1 mg/L, the EC_{50} for the tank mix including Rodeo and R-11 surfactant was 29.9 mg/L, and the EC_{50} for the R-11 surfactant alone was 1.0 mg/L.

The lowest of these NOEC and LC_{50} values (10 mg/L) for glyphosate or glyphosate/surfactant mixtures is well above the maximum glyphosate concentration of

0.026 mg/L reported by Paveglio *et al.* (1996) and the immediate maximum geometric mean glyphosate concentration of 0.174 mg/L reported by Patten (2002). Therefore, these data indicate that impacts to aquatic invertebrates due to post-application water concentrations of glyphosate are unlikely in experimental conditions. Impacts in estuarine conditions with high concentrations of suspended sediment, which interfere with glyphosate activity, would be even less likely.

Kubena *et al.* (1997) conducted sediment and water toxicity studies on marine invertebrates (oysters and amphipods). The LC_{50} values for Rodeo and surfactant in water ranged from 200 to 400 mg/L, and the LC_{50} values in sediment ranged from 1000 to 6000 mg/kg. These LC_{50} values are well above the highest measured geometric mean sediment concentrations of 2.3 mg/L reported by Kilbride *et al.* (2001) and Patten (2002).

Field studies of glyphosate/surfactant applications to tidal mudflat invertebrate communities in Willapa Bay, Washington, agree with laboratory tests, which indicate low potential for adverse impacts to benthic invertebrates. Sampling of benthic invertebrates in mudflats up to 199 days after glyphosate/surfactant (X-77) applications revealed no short-term or long-term effects. Short-term laboratory tests of amphipods exposed to glyphosate and surfactants did not affect survival even at high concentrations relative to post-spray field conditions (Kubena 1996).

Fish

***Imazapyr*.** As detailed in both the 2003 Entrix and 2004 SERA reports, a number of standard bioassays submitted to the U.S. EPA in support of the registration of imazapyr indicate very low toxicity to fish with 96-hr LC_{50} values greater than 100 mg/L in most studies. According to U.S. EPA's ecotoxicity classification for aquatic organisms (see Table A-6), these values classify imazapyr as practically non-toxic, the lowest category for addressing acute risk to aquatic organisms from use of chemicals. (U.S. EPA 2005.) A recent study suggests that both Habitat® and Rodeo® have relatively low toxicity to juvenile rainbow trout. The LC_{50} determined for Arsenal® (a terrestrial formulation identical to Habitat® that did not contain any surfactants) was determined at 22,305 mg imazapyr a.e./L. (King *et al.* 2004.)

One study reported much lower 96-hr LC_{50} values of 4.7 mg/L for Nile tilapia (*Tilapia nilotica*) and 2.7 mg/L for silver barb (*Barbus genionotus*). (Supamataya et al. 1981 in SERA 2004.) Although the herbicide used was not specified, it is likely that a formulation was used rather than the technical grade active ingredient. Historically imazapyr herbicides contained surfactants and a formulation that removed the surfactant was only developed in 1992. The use of an herbicide containing surfactants might explain the considerably lower LC_{50} values. The 2004 SERA report used the lowest LC_{50} value from this study, 2.7 mg/L, for their risk assessment despite some reservations about the study due to the fact that they only had access to its abstract and because the species studied were not native to the U.S. Nevertheless, the 2004 SERA report assumed that, even though the study was not well documented, the response of these apparently sensitive species may well encompass the response of other sensitive species native to the U.S. (SERA 2004, p. 4-22.) This conclusion is supported by a study that examined the comparative sensitivity of eight ESA-listed fish species to standard test organisms exposed to five different pesticides or metals in order to validate the use of surrogate species as a predictive tool in toxicological assessments. Based on their findings, the authors concluded that a safety factor of two would provide a conservative estimate in risk assessments for listed cold-water, warm-water and euryhaline fish species. (Sappington *et al.* 2000 in Entrix 2003, p. 49.)

Glyphosate. Acute toxicity studies with warm and cold water fish indicate that technical glyphosate is slightly to practically non-toxic. (U.S. EPA 1993.) Acute toxicity LC_{50} values were reported at 86 mg/L in rainbow trout, 120 mg/L in bluegill sunfish, and 168 mg/L in harlequin. (ExToxNet 2005.) Chronic toxicity studies with a terrestrial formulation of glyphosate, Roundup®, found no significant adverse effects on growth, carcinogenicity, feeding, and agonistic behavior in rainbow trout fingerlings. The authors concluded that sublethal levels of the formulation are relatively non-toxic. (Morgan & Kiceniuk 1992 in WS FEIS 1993.) A recent study with the aquatic formulation Rodeo® determined the LC_{50} for juvenile rainbow trout at 782 mg glyphosate a.e./L.

Giesy *et al.* (2000) reviewed the data available on glyphosate toxicity to fish. Although some data were available for anadromous species, it appears that all tests were conducted using freshwater test methods. Acute toxicity LC_{50} values for glyphosate tested as isopropylamine salt ranged from 97 to greater than 1,000 mg/L and NOEC values ranged from <97 to 1,000 mg/L. Data compiled by Ebasco (1993) on one-day acute toxicity tests indicate EC_{50} values ranging from 12.8 mg/L to 240 mg/L.

The lowest of these NOEC and LC_{50} values (12.8 mg/L) for glyphosate or glyphosate/surfactant mixtures is well above the maximum glyphosate concentration of 0.026 mg/L reported by Paveglio *et al.* (1996) and the immediate maximum geometric mean glyphosate concentration of 0.174 mg/L reported by Patten (2002). Therefore, these data indicate that impacts to fish due to maximum post-application water concentrations of glyphosate are unlikely in experimental conditions. Impacts in estuarine conditions with high concentrations of suspended sediment, which interfere with glyphosate activity, would be even less likely.

Birds

Imazapyr. Only few toxicity studies exist for birds. No adverse effects were noted at imazapyr concentrations of up to 5,000 ppm in the diet. Based on the highest doses tested and the U.S. EPA ecotoxicity categories (*see* attached Table A-5), these results suggest that imazapyr is moderately or less toxic orally to birds. No data exist for the potential toxicity of imazapyr to shorebirds. (Fletcher 1983a,b,c,d in SERA 2004.) No studies exist on toxicity to raptors or on preening or inhalation exposure potentials.

***Glyphosate*.** Effects of glyphosate on birds have been tested on mallard ducks (dabbling ducks which ingest wetland sediment along with seeds, insects, and vegetation) and bobwhite quail. Glyphosate is no more than slightly toxic to birds. Several single-dose acute oral studies indicate that glyphosate is practically non-toxic to upland birds and only slightly toxic to waterfowl. (U.S. EPA 1993.) As with mammals, very high dietary concentrations of glyphosate (a 4,640 mg/kg dietary concentration) resulted in no adverse reactions such as weight loss or mortality (Ebasco 1993). Chronic exposure studies with glyphosate determined a no-observed-effect concentration (NOEC) of 1,000 ppm in the diet. (Heydens 1991 in WS FEIS 1993.) Little or no data are available on toxicity of surfactants to birds.

Mammals

***Imazapyr*.** Based on U.S. EPA ecotoxicity criteria, imazapyr is considered practically non-toxic to mammals via oral or dermal administration based on acute and chronic studies conducted with a variety of mammalian species. For example, the reported acute oral LD_{50} for technical imazapyr in rats is greater than 5,000 mg/kg body weight (b.w.) Rats were observed to rapidly excrete imazapyr in urine and feces with no residues detected in their liver, kidney, muscle, fat, or blood. No observable effect was noted for any formulation of imazapyr administered dermally. Very few inhalatory studies were performed and none tested concentrations high enough to determine acute toxicity. Inhalatory effects at sublethal concentrations (<5 mg/L aerosol) were found with technical grade imazapyr resulting in slight nasal discharge and congested lungs. Technical grade imazapyr and imazapyr isopropylamine salt were both found to be moderately irritating to rabbit eyes with complete recovery within 7 days. Technical grade imazapyr is reported as mildly irritating to rabbit skin. Commercial formulations of imazapyr appear to be less toxic via dermal exposure. (Entrix 2003, p. 42-44.) Chronic and subchronic toxicity studies with imazapyr with dogs, mice, and rats did not suggest any systemic toxic or carcinogenic effects. (SERA 2004.)

Glyphosate. Glyphosate has been determined to be practically non-toxic to mammals by ingestion with an acute oral LD_{50} of 5,600 mg/kg b.w. in rats. The no-observed-effect level (NOEL) for chronic toxicity to rats has been determined at 362 mg/kg b.w./day (8,000 ppm) and LOEL at 940 mg/kg b.w./day (20,000 ppm). (USDA 1981; Monsanto 1983; both in WS FEIS 2003.) The reported acute LD_{50} values for dermal effects range from >5,000 to 7,940 mg/kg for rabbits. Subchronic oral toxicity studies of glyphosate with rats and dogs indicate that oral does of up to 2,000 ppm do not significantly affect behavior, survival, or body weight. Laboratory studies of the chronic effects of glyphosate show that it is slightly to practically non-irritating to rabbits' eyes. No significant reproductive, teratogenic, mutagenic, or carcinogenic effects from exposure to concentrations of up to 300 ppm were reported in 20-year laboratory studies with rats, dogs, rabbits, and mice.

Little is known about potential interactive effects between applied imazapyr or glyphosate/surfactant solutions and cumulative loads of herbicides, insecticides, detergents, perfume agents, and many other organic contaminants in the San Francisco Estuary. It is reasonable to assume that cumulative, interactive effects occur in organisms of the Estuary, but the complexity of multiple interactions in uncontrolled field conditions makes definitive research difficult.

In practice, total dosages of imazapyr or glyphosate/surfactant solutions applied in field conditions (amount of solution applied, and concentration, and the number of re-applications to eradicate survivors) depends on many factors which are independent of the physiology of imazapyr, glyphosate or the surfactants themselves. The physiological activity and health of the plant, interference with spray coverage by persistent dead leaves or sediment films, all can affect the percent kill of vegetation, and the ability of regenerative buds to survive and re-establish the population. Regeneration requires re-application of herbicide or other eradication methods.

7. DESCRIPTION OF ALTERNATE, NON-CHEMICAL CONTROL METHODS

The *Spartina* Control Program implements a number of non-chemical control methods in situations where environmental impacts can be reduced, sites are appropriate for volunteer efforts and educational opportunities, or where public demand dictates. These methods are especially appropriate for small, newly establishing infestations and/or for some of the final cleanup of sites after control efforts have reduced the infestation down to small remaining patches. Non-chemical control methods are also a great way to engage the community around a site because they foster volunteer stewardship efforts and public outreach. During the development of the Site-Specific Plans for control of invasive *Spartina* around the Bay, the *Spartina* Control Program evaluated every possible known control method that could be used. A number of criteria were used in the evaluation including efficacy at controlling the *Spartina*, human health and safety, damage to the marsh habitat and/or other aspects of the environment, impacts on water quality, feasibility of applying the method in the salt marsh, cost, etc. Several non-chemical methods (hand-pulling and manual excavation, covering/blanketing, and mechanical excavation or dredging) have been incorporated into the Site-Specific Plans for 2005-2007. The remainder of the methods that were evaluated were found to have significant limitations, and are not part of the *Spartina* Control Program's current plans. However, some of these methods may be used in conjunction with our selected control methods at a later date. The entire set of possible control methods that were evaluated are discussed below, starting with the methods that were selected and incorporated into the plans.

ISP-selected Non-chemical Control Methods

Hand-pulling and manual excavation

Manual removal methods are the simplest technology for removal of cordgrass. Manual removal includes pulling cordgrass plants out of marsh sediments or using hand tools such as spades, mattocks, or similar tools to cut away as much cordgrass as possible within reach. Manual removal methods are effective primarily at removing aboveground plant parts, but are less effective at removing belowground rhizomes (the horizontal underground stem that sends out roots and shoots from buds) that rapidly regenerate shoots. Unless digging removes the entire marsh soil profile containing viable rhizomes and buds, its effect is equivalent to pruning (see *Mowing, burning, pruning, and flaming*, below). The vigor with which remaining rhizomes resprout and regrow is often proportional with the severity of the disturbance. Frequent re-digging and maintenance is needed to exhaust rhizome reserves of energy and nutrition, and the population of buds capable of resprouting.

Manual removal is most effective on isolated seedlings, or very young discrete clones (asexually reproduced colonies of cordgrass) or clumps, where they are infrequent. Manual excavation in tidal marshes is extremely labor-intensive. Most cordgrass colonies occur in soft mud, where footing needed for digging is impossible or hazardous, even for workers on platforms, mats, or snowshoe-like boots adapted for walking on mudflats. Dug plants with roots left in contact with moist soil may retain viability and regenerate in place or disperse on high tides to establish new populations.

Disposal of manually removed material, especially root/rhizome systems, is problematic. On-site disposal in marshes may cause additional marsh disturbance and may result in spread of invasive cordgrass by regeneration of viable roots. Where manual removal occurs next to levees, salt ponds, or other non-tidal environments, local disposal may be feasible. Disposal of manually removed materials may also be accomplished with specialized low-ground-pressure equipment (amphibious vehicles), but the number of passes needed to transport materials also increases marsh disturbance.

Mechanical excavation and dredging

Mechanical removal in marshes uses equipment specially designed for working in semi-terrestrial, semi-aquatic wetland environments. Excavation and dredging are accomplished using (1) amphibious dredges fitted with excavators, clamshells, or "cutterhead" dredges, or (2) excavators working from mats (large wood pile supports placed flat on geotextile fabric placed over the marsh surface). Some locations allow use of conventional shallow-draft, barge-mounted dredging equipment working within reach of marsh from the margins of navigable channels, particularly at high tide. Where cordgrass colonies lie within the limited reach of track-mounted excavators working from levees, mechanical removal also can be performed without entry of equipment to aquatic or wetland environments.

Another mechanical technique is maceration or pulverization of soil and plant remains on site using modified agricultural equipment, "chewing" them into particles too small to be viable or regenerate. Floating maceration equipment has been used in inland waterways to control submerged aquatic vegetation. The Control Program may support research and development of this method for use in the baylands environment, and would utilize this method if it were shown to be effective and reliable with mitigable impacts.

Mechanical excavation working to the full depth of the rhizome system (up to 1 foot) in tidal marshes has the potential to be significantly more effective than manual excavation. Similarly, maceration techniques that almost completely destroy both aboveground and belowground living mass of cordgrass have high potential effectiveness. Both techniques also have significant limitations in the San Francisco Estuary, however. Excavators working from levees have an inherent limitation of short reach or access distance, usually a working distance of less than 20 feet for the size equipment that typical levees could bear. Floating barges with clamshell or cutterhead dredges, in contrast, would need to work at high tides within about 70 feet of the leading edge of cordgrass vegetation. Excavators have sufficient reach to dispose of excavated marsh soil and biomass in non-wetland areas, on levees, or in aquatic habitats such as salt ponds, which lack vegetation.

Heavy equipment often is used within the Estuary's tidal marshes for purposes other than eradication of cordgrass, including removal of large debris hazards and contaminated materials, and construction or maintenance of ditches or canals. Most of this work is done on mats, to distribute the weight of equipment and protect underlying vegetation. These actions are usually aimed at operations that are highly localized (points or narrow alignments) in the marsh, and usually on the relatively firm marsh plain. Even there, equipment may become mired in soft spots, and removal of mired equipment can damage the marsh. In contrast, to maintenance-type work, removal of invasive cordgrass involves a mosaic pattern for operations, and occurs most often in the low marsh and mudflats, which do not easily support mats and geotextile fabrics. Thus, control methods based on excavators working on mats would be most applicable to localized, large patches of invasive cordgrass on the marsh plain. Some tidal flats invaded by cordgrass occur on sandy deltas with intertidal sand bars (e.g., San Leandro, San Lorenzo Creek) where equipment could be staged, but this situation is unusual. The feasibility of using mechanical excavation or dredging methods at a particular location would be determined based on site-specific conditions.

Covering/blanketing

This is another technique that is aimed at exhausting the reserves of energy and nutrition in cordgrass roots and rhizomes and increasing environmental and disease stress. Covering typically involves securing opaque geotextile fabric completely over a patch of cordgrass. This excludes light essential to photosynthesis (transformation of solar energy to food energy), and "bakes" the covered grass in a tent of high temperature and humidity.

This technique may be used for discrete colonies (clones) where the geotextile fabric can be fastened to the marsh surface securely with stakes for a sufficiently long period of time. High tides, high winds, and tide-transported debris common in tidal marshes often make this difficult or impossible in some situations. Care must be taken to cover the entire clone to a distance sufficient to cover all rhizomes. If rhizomes spread beyond the reach of the blanketing cover, rhizome connections to exposed, healthy stems can translocate (pipe) foods to the stressed, starving connected portions of the clone under the fabric, and increase overall survival. Staking geotextile tents on soft mudflats is very difficult, and may make this method infeasible in many situations.

Wrack (piles or lines of drifted debris and detritus from tidal sources) also is capable of smothering cordgrass and other salt marsh plants. Wrack can be created artificially by placing temporary debris piles on the marsh surface, but cannot be stabilized for long (usually no longer than the highest December-January or June tides or winter storm surges). Their duration at any position in the marsh depends on the frequency and height of tides. The lower in the intertidal zone, the less stable the position of a wrack pile is likely to be. This technique would be used only for small colonies, and would depend on locally available accumulations of organic tidal debris.

Other Non-chemical Methods Evaluated

Mowing, burning, pruning, and flaming

Cordgrasses are well adapted to disturbances that "crop" or otherwise remove aboveground biomass. A single event that removes living or dead aboveground cordgrass biomass generally stimulates cordgrass growth, and as soon as a cordgrass stand refoliates, it begins to "recharge" its roots and rhizomes with new food reserves. If vegetation is removed with frequency, roots and rhizomes are prevented from regenerating reserves of energy and nutrition and cordgrass begins to die back as its organs of regeneration and storage become exhausted. If the cordgrass is mown close to the mud surface, it also severs the connections between leaves and roots that transport gases to roots growing in extremely anoxic (oxygen-deprived) waterlogged sediment and further stress the plant.

Repeated close mowing may be used to increase physiological stress to a point that cordgrass cannot regenerate; frequent burning would have similar effects. The use of pruning, burning, and mowing for cordgrass eradication in open mudflats and marshes would require very frequent treatment of all aboveground growth until the cordgrass rhizome/root systems become exhausted. For robust stands of Atlantic smooth cordgrass, this may require weekly treatment for more than one growth season.

Controlled burning may be used in some situations to remove vegetation prior to other treatments, or to prevent pollen and seed dispersal in founder colonies invading new sites.

Burning would be used only in suitable locations, and only during periods of low-wind conditions (especially early morning), when fire hazards in succulent vegetation of tidal pickleweed marshes would be manageable. Ignition, however, may be difficult in cordgrass stands on mudflats.

Selective pruning (partial mowing with "weed-whackers" or flaming with hand torches) may be used to remove flowerheads and seedheads of discrete colonies to prevent flow of pollen from contaminating seed production of native cordgrass, and to prevent seed production within founding colonies. However, pruning would have little or no effect on the clone's growth rate and must be followed up with other methods to control spread.

Mown vegetation without viable seeds or propagules may be left in place or removed from the site. Vegetation containing viable seeds or propagules would require removal from the treatment site and disposal in a suitable area not conducive to cordgrass growth.

Crushing and mechanical smothering

This method uses amphibious track vehicles to trample new plant shoots and stems, and cover them with a layer of sediment. The objective is to smother the plant by preventing the use of stems to transport oxygen to its roots and rhizomes. The method would typically be used in the fall, and ideally a period of time after mowing, when young shoots and stems have developed. This method has been used with some success in Washington State, but has not yet been used in the San Francisco Estuary.

Flooding and draining

Flooding and draining techniques entail constructing temporary dikes or other structures to impound standing water or remove water to kill emergent vegetation. Cordgrasses are intolerant of permanently flooded or stable, dry conditions, and are generally absent in the diked nontidal salt marshes of the Estuary. Salt evaporation ponds, managed waterfowl ponds, and completely diked pickleweed marsh exclude cordgrasses, native and non-native alike. Atlantic smooth cordgrass and English cordgrass are capable of invading tidal marsh pools (salt pans) subject to irregular tidal influence (Campbell et al. 1990, P. Baye, pers. observ.), but they are not likely to survive in typical diked wetlands.

When tidal marshes are diked and drained rather than flooded, they undergo rapid physical and chemical changes. Organic matter decomposes when microbes are exposed to air; clays shrink when dewatered; and sulfides formed in oxygen-free mud transform to sulfates forming strong acids (Portnoy, 1999). Therefore, diking and draining, although conceivably effective for killing cordgrass, would adversely impact marsh soils and restoration, and the longer salt marsh soils are diked and drained the more difficult these adverse soil changes are to reverse. For these reasons, diking and draining only would be used in critical situations where no other method is feasible, and only after careful evaluation and planned mitigation. Diked salt marsh soils that remain permanently flooded undergo relatively slower and less significant changes. Diked flooded salt marshes would eliminate existing standing vegetation, but are readily re-colonized by youthful salt marsh vegetation if the diking is brief.

Isolating the treatment area for flooding or draining may be accomplished by constructing temporary dikes or by closing openings in existing dikes. Temporary constructed dikes need not be large to accomplish treatment. Low earthen berms (about one foot above marsh plain elevation), constructed using low-ground pressure amphibious excavators, could be built around large colonies of cordgrass within open marsh plains. Alternatively, water-filled geotextile tubes ("inflatable dams"), analogous with inflatable cofferdams used in aquatic construction/dewatering operations, may be used. Upon completion of treatment, berms would be graded down to marsh surface elevation, and inflatable dams removed. Temporary dike structures may be difficult to construct in tidal mudflats. Mud-flat sediments are usually too soft to "stack" into berms, and firmer material placed on fluid or plastic muds simply subsides into the flats. Similarly, inflatable dams may not be feasible for softer tidal flats.

Many populations of non-native cordgrasses have invaded marshes restored by breaching dikes within former diked baylands, where most of the original dikes remain. In these situations, a dike-enclosed tidal marsh could be temporarily re-closed ("choked") by placing a sheetpile barrier in the existing breach, thus creating a temporary lagoon and effecting mass cordgrass eradication. Water control structures (adjustable tidegates) may be installed to enable marsh managers to maintain water depths lethal to cordgrass, suitable diving duck habitat, and adequate water quality. Marsh recolonization is expected to proceed rapidly following restoration of tidal flows.

An alternative form of treatment, intermediate between flooding and draining, would be to combine impoundment of water with deliberate solar evaporation, creating hypersaline lagoons. Hypersaline conditions would make the habitat transformation even more rapidly lethal for invasive cordgrass. Restoring tidal flows to temporary salt ponds, however, may require dilution of brines, which could increase cost.

8. HERBICIDE APPLICATION AREAS FOR 2007

Twenty-six sites, comprising 157 sub-areas and approximately 400-500 acres of non-native *Spartina*, are slated for control during the 2007 *Spartina* Treatment Season (Figure 3), and 138 of these will potentially be treated with herbicide. Most of these sites are being re-treated for the second or third year, hence the significant reduction in treatment area from 1,500 acres in 2006. Aquatic herbicide was determined to be the most efficacious, feasible, and least impactful method for *Spartina* control following a thorough evaluation of the available control methods described above. Each site has been evaluated taking into account many factors including site access, endangered species issues, habitat sensitivity, the infestation’s susceptibility to non-chemical control methods, partner involvement, public comment, and other factors. A brief description of each site follows including the herbicide delivery systems(s) to be used and an identification of the ISP Partner involved in treatment work on the site. Detailed maps of the each site can be found in Appendix 2.

Site 01 – Alameda Flood Control Channel, Alameda County

The Alameda County Flood Control Channel (ACFCC) is a large, unlined, trapezoidal channel that runs from east to west through Hayward, Alameda County, draining a nearly 800 square mile watershed into the San Francisco Bay. The levees on both sides of the ACFCC are topped with multi-use public trails that are part of the San Francisco Bay Trail and Coyote Hills Regional Park. Downstream from Ardenwood Blvd., beyond the levees to the north, are both active and inactive commercial salt ponds, with an industrial facility and parking lot along the furthest upstream levee. To the south are active salt ponds, seasonal wetlands, and Coyote Hills Regional Park. There are currently no housing units, schools or other similar facilities within this lower reach.

Figure 3. Location of 2007-2011 *Spartina* Treatment Sites Within the San Francisco Estuary and Adjacent Outer Coast Marshes. Each treatment site is comprised of one to 25 "sub sites," which are identified by letters (a through z) in project plans and documents.

The combined infestation of the six sub-areas of the Alameda Flood Control Channel comprised one of the largest S*partina alterniflora* hybrid infestations in San Francisco Bay. The ISP's 2004 mapping effort estimated a total of roughly 200 contiguous acres of *S. alterniflora*/ hybrids on this site spread over approximately 470 acres (43%) of salt marsh and tidal mudflats. The treatments in 2005 and 2006 have reduced the infestation by at least 75%. The primary treatment method at this site is aquatic herbicide, which will be applied by helicopter, conventional spray truck, and tracked amphibious vehicle. Partners on this site include the Alameda County Flood Control District and the California Wildlife Foundation. Note that this is a complex site composed of multiple sub-areas. Please refer to the Site Specific Plan for detailed descriptions of the sub-areas and the associated treatment methods.

Site 02 – Bair & Greco Island Complex, San Mateo County

The Bair & Greco Island complex encompassed by this plan is located in the southwest portion of the San Francisco Bay Estuary. The northern edge of the complex is at Belmont Slough on the border of Foster City and Redwood City, including the marshes of Brewer Island just south of the San Mateo Bridge. The southern border of the complex is the Union Pacific railroad line just south of the Dumbarton Bridge. The site includes marsh islands, active and inactive commercial salt ponds, six large sloughs with numerous smaller channels, and other bay front marsh that is part of the San Francisco Don Edwards National Wildlife Refuge (DENWR).

The Bair & Greco Island complex contains many different marsh systems, all of which are impacted to varying degrees by *Spartina alterniflora* hybrids. Of the roughly 3,060 acres of Baylands within the complex, there were approximately 216 acres (7%) infested with non-native *Spartina* in 2005. Two years of effective herbicide treatments in this complex leave less than 50 acres to treat/retreat in 2007. The primary treatment method at this site is aquatic herbicide, which will be applied by helicopter, conventional spray truck, backpack sprayer, tracked amphibious vehicle, and boat. Partners on this site include the U.S. Fish and Wildlife Service, Don Edwards National Wildlife Refuge and the San Mateo County Mosquito Abatement District. Note that this is a complex site composed of multiple sub-areas. Please refer to the Site Specific Plan for detailed descriptions of the sub-areas and the associated treatment methods.

Site 03 – Blackie’s Pasture, Marin County

Blackie’s Pasture is a small City of Tiburon park located along the shoreline of Richardson Bay, adjacent to Tiburon Boulevard. With the ample parking provided at the park, it is heavily used by the public for passive recreation. The park is comprised of a 0.7-acre pasture, a small creek channel (“Blackie’s Creek”) along the eastern edge of the pasture, and a shoreline area that includes the channel mouth, a small open mudflat (fed by sediment delivered by the creek), and landscaped pathways and picnic areas. The total area of non-native *Spartina* at the Blackie’s Pasture site was around 0.8 acre in 2005, divided between two sub-areas. This has been reduced to several hundred square feet that will be treated in 2007. The upper portion of this site is represented by the Blackie’s Creek Channel (Sub-Area 3a), wherein *Spartina alterniflora* hybrids dominated what was previously an open channel. *Spartina densiflora* and *Spartina alterniflora* hybrids dominated the mouth of Blackie’s Creek (Sub-Area 3b), readily hybridizing with the native *Spartina foliosa* stand there. Some excavation of the upper channel occurred in 2005 as part of a restoration project, but only the invasive *Spartina* in the center of the creek was actually removed; the remainder was treated in 2006. The primary treatment method at this site is aquatic herbicide, which will be applied by backpack sprayer. Partners on this site include the City of Tiburon Public Works and the Tiburon Audubon Society.

Site 04 – Corte Madera Creek Complex, Marin County

The Corte Madera Creek complex is located on the west side of the North San Francisco Bay in Marin County, south of the San Quentin peninsula and San Rafael Bay. The complex consists of a wide corridor stretching upstream from the mouth of Corte Madera Creek to the uppermost point of non-native *Spartina* growth in this watershed at about 2.2 miles from the mouth. The entire Corte Madera Creek corridor is heavily developed with upscale residential and commercial facilities. The Corte Madera Creek complex is comprised of 11 distinct sub-areas that occur on both public and private lands, each of which will require different treatment and public outreach approaches.

The infestation at the Corte Madera Creek complex was still in a relatively early stage of establishment, with approximately 12 acres scattered over 318 acres, or 4% of the total marsh area. The infestation at this complex contains some unique features, including the only infestation of *Spartina anglica* in the Bay, as well as the first documented case of *Spartina densiflora* hybridizing with the native *Spartina foliosa*. Most of the sub-areas have small *S. densiflora* infestations (less than 0.5 acre), enabling manual control to be used in conjunction with spot herbicide treatments. One sub-area also has *Spartina alterniflora* hybrids, bringing the overall site total to three of the four invasive cordgrass species currently found in the Bay.

The Marin Conservation Corps conducted a great deal of manual removal throughout the winter of 2005-2006, and this method was highly effective. Most of the areas appropriate for this control method have now been completed, and the primary method for 2006 involved herbicide application. These 2006 applications were very effective, but many sub-areas need some degree of retreatment with aquatic herbicide in 2007. A few of the sites that were controlled by herbicide in 2006 will be revisited this season to manually pull/dig the few plants that have resprouted or emerged from the seedbank. Partners on this site include the Friends of the Corte Madera Creek Watershed, California Department of Fish and Game, California State Lands Commission, College of Marin, City of Larkspur, Golden Gate Bridge Highway and Transportation District, Marin County Parks and Open Space District, and the Marin County Flood Control and Water Conservation District. Note that this is a complex site composed of multiple sub-areas. Please refer to the Site Specific Plan for detailed descriptions of the sub-areas and the associated treatment methods.

Site 05 – Coyote Creek & Mowry Slough Area, Santa Clara County

The area encompassed by this Site-Specific Plan includes approximately 3,652 acres of marshland within the San Francisco Don Edwards National Wildlife Refuge that lie between Coyote Creek to the south and the Dumbarton Bridge to the north. The site is surrounded entirely by marsh and salt ponds, and there is very little public access, except for a portion of the Bay Trail along part of Newark Slough (Sub-Area 5c). Within this area, the sub-areas include recently restored tidal marshes, freshwater ponds and upland islands, highly complex and diverse historic marsh habitats that include channels, high marsh, mudflats and pans, thin strip marshes, open mudflats, creek channels and mouths, and sandy beach areas.

The pioneering infestation of *Spartina alterniflora* hybrids in the Coyote Creek and Mowry Slough complex is still very limited in its distribution. However, though the acreage is still relatively small, the clones are distributed throughout the habitat types described above. In sum, these infestations covered approximately 15.3 acres in 2005 scattered over this very large marshland complex, which is equal to just 0.4% of the area. Much of this area was treated for the first time in 2006 using a directed herbicide application tool (spray ball) that the ISP developed with PJ Helicopters of Red Bluff, CA. Efficacy was at least 50% from the 2006 applications, leaving approximately 5-7 acres to treat in 2007. The primary treatment method at this site is aquatic herbicide, which will be applied by spray ball or broadcast from helicopter, conventional spray truck, backpack sprayer and tracked amphibious vehicle. The partner on this site is the U.S. Fish and Wildlife Service, Don Edwards National Wildlife Refuge. Note that this is a complex site composed of multiple sub-areas. Please refer to the Site Specific Plan for detailed descriptions of the sub-areas and the associated treatment methods.

Site 06 – Emeryville Crescent, Alameda County

The Emeryville Crescent marsh is a 103.5-acre, fringing mixed pickleweed (*Salicornia virginica*) marsh shoreline between Powell Street in Emeryville and the eastern landfall of the Oakland Bay Bridge. Two sub-areas, Emeryville Crescent East (6a) and Emeryville Crescent West (6b), have been delineated due to the historical ownership and maintenance of the site. The site abuts an extremely heavily developed area on the east side of the Bay, with Interstate 80/580 directly adjacent to the east, and the approach to the San Francisco Bay Bridge adjacent to the south. Local anglers, dog-walkers, and other recreational groups frequently use the marshlands included in this site. Illegal activities such as dumping and littering, unauthorized camping, and public inebriation also occur along the edges of, and sometimes within, the marshlands of this site.

The non-native *Spartina* infestations at Emeryville Crescent are in the early stages of establishment on the site. The individual locations of these plants were scattered across both of the sub-areas, but their overall acreage was small in 2005, at less than 2.6 acres or 2.5% of the combined marsh acreage. The infestation is located mainly along the bay edge of the marsh, adjacent to the open mudflats on the outer edge of the site, with a few scattered clones establishing on the interior portions of the marsh within Sub-Area 6b. Treatment in 2007 will be needed on just several hundred square feet after two years of successful applications. The primary treatment method at this site is aquatic herbicide, which will be applied by conventional spray truck, backpack sprayer, and tracked amphibious vehicle. Partners on this site include the California Department of Parks and Recreation and the East Bay Regional Parks District.

Site 07 – Oro Loma Marsh, Alameda County

Oro Loma Marsh is a large, 324-acre, recently restored salt pond located on the eastern shore of the San Francisco Bay Estuary adjacent to the town of San Lorenzo, about 1.5 miles south of the Metropolitan Oakland International Airport. The marsh is surrounded by levees, with Bockmann Channel and Sulfur Creek bordering the marsh to the north and south respectively. The San Francisco Bay Trail, a multi-use public recreational pathway, utilizes the levee to the west of Oro Loma, and the Southern Pacific Railroad borders the marsh to the east. The surrounding area includes various industrial and commercial developments to the north and south including a sewage treatment plant, electrical substation, and capped landfill. Beyond the railroad to the east are residential developments, the Skywest Golf Course, and Hayward Municipal Airport, with I-880 approximately 0.5 mile from the marsh edge.

The entirety of the Oro Loma Marsh site was infested with *Spartina alterniflora* hybrids across both Sub-Areas prior to the very successful helicopter treatment in 2005, totaling approximately 100.0 acres (31% of the marsh). This was one of the largest infestations of *S. alterniflora* hybrids in the eastern Central Bay, and was adjacent to several other large infestations including sites along the San Leandro/ Hayward shoreline. A very successful follow-up treatment occurred in 2006, leaving less than 5 acres scattered mainly in the Oro Loma East that will be treated in 2007. The primary treatment method at this site is aquatic herbicide, which will be applied by helicopter on the remaining stands. The partner on this site is the East Bay Regional Parks District.

Site 08 – Palo Alto Baylands, Santa Clara County

The Palo Alto Baylands is a 1,030-acre nature preserve and park complex owned by the City of Palo Alto and located on the bayfront south of the Dumbarton Bridge. The site includes those areas to the north and south of Charleston Slough, and may extend to the northernmost tip of marshland on the southeast portion of the outlet of Charleston Slough – that land within the city limits of Palo Alto. The site is part of a large expanse of intact native *Spartina foliosa* and pickleweed (*Salicornia virginica*)/gumplant (*Grindelia* sp.) marsh habitat. The park has high visitation on the established pathways through the marsh, and serves as an educational center for birdwatchers, naturalists, local schools, and the public. Other recreational users of the preserve include hikers, kayakers, anglers, bikers, joggers and many others.

The pioneering infestation of *S. alterniflora* hybrids on this site covered approximately 1.0 acre in 2005, scattered along the bayfront, mostly south of the Baylands Nature Interpretive Center. Treatment in 2005 & 2006 has reduced this infestation by approximately 80%. There are several main areas of infestation: the southeast side of the "Yacht Club Bay" near Mayfield Slough, clones near Hooks Point and Hooks Island, and scattered plants along the bayfront from Mayfield Slough to Charleston Slough. The primary treatment method at this site is aquatic herbicide, which will be applied by conventional spray truck, backpack sprayer, and boat. Partners on this site include the City of Palo Alto and Palo Alto High School.

Site 09 – Pickleweed Park, Marin County

Pickleweed Park is an 18-acre City of San Rafael Park located on the edge of San Rafael Bay in the northwestern San Francisco Bay Estuary. It is bounded to the north by San Rafael Creek and to the south by East Canal Street. Bordering the park on the east side is the 10-acre Tiscornia Marsh, a thin band of high marsh pickleweed/gumplant habitat, which grades abruptly from a 2 to 3 foot-high escarpment to an extensive mudflat extending bayward. This band of marshland tapers as it extends southward along the park boundary, and becomes very thin as it curves eastward along the riprap of a levee surrounding an area filled for development. There is an east/west wooden service walkway through the marsh that provides access to the Pacific Gas and Electric (PG&E) power line tower adjacent to the site.

There is an establishing population of *Spartina densiflora* within the fringing marshlands of the park. These plants are at their greatest density in the marsh near the outlet of San Rafael Creek. The plants form a dense stand on the Bay edge surrounding the escarpment, near an electrical tower. Scattered plants extend southward from this main area along the Bay edge, and then east and southeast to Shoreline Park. The total infestation size of *S. densiflora* on the site was approximately 0.05 acres (2200 ft^2). In spring 2005, a pioneering infestation of *S. alterniflora*/ hybrid was also discovered just south of the PG&E walkway. Treatment in 2005 and 2006 were highly effective and just a handful of plants will need to be treated in 2007. The primary treatment method at this site is aquatic herbicide, which will be applied by backpack sprayer. Partners on this site include the Tiscornia Estate Company and Cherokee-Simeon, LFR Levine Fricke.

Site 10 – Point Pinole Regional Shoreline, Contra Costa County

Point Pinole Regional Shoreline is a 2,315-acre park owned by the East Bay Regional Parks District. It is located to the west of the city of Richmond, in Contra Costa County. Point Pinole opened to the public in 1973 after the property was acquired from Bethlehem Steel. Bethlehem had acquired the land in the early 1960s from Atlas Powder Co., one of several firms that had manufactured gunpowder and dynamite there for almost 100 years. The park occupies a short peninsula composed of a main upland core with open, grassy parklands interspersed with predominantly eucalyptus woodlands. Along the northern portion of the park, a wide border of high marsh pickleweed characterizes Whittell Marsh, Sub-Area 10a. The southern portion of the park, Sub-Area 10b is a narrow band of tidal marsh grading quickly over a 10-20 meter span from high marsh pickleweed to sandy mudflat.

The non-native *Spartina* infestations at Point Pinole are in the early stages of establishment. The individual locations of these plants are scattered within both of the Sub-Areas, but their overall acreage is small, reduced from 0.7 acre in 2005 to several hundred square feet to be retreated in 2007. The primary treatment method at this site is aquatic herbicide, which will be applied by backpack sprayer. The partner on this site is the East Bay Regional Parks District.

Site 11 – Southampton Marsh, Contra Costa County

Southampton Marsh is the largest extant marsh within the Carquinez Strait. Its roughly 175 acres are located within the 720-acre Benicia State Recreation Area, Solano County. Highway 780 borders the park on the north and east, Southampton Bay on the south, and on the west stands the residential development of Vallejo. Cyclists, runners, walkers and roller skaters use the park's 2.5 miles of road and bike paths, which circle the perimeter of the park. The Marsh lies in the central portion of the park, and consists mostly of high marsh pickleweed/gumplant habitat, with a deep main channel and several smaller channels throughout. *Cordylanthus mollis* ssp. *mollis* (soft bird's-beak), an endangered plant species, can be found in some of the high marsh areas of the site. Access to the marsh is restricted to park personnel and researchers to protect the *C. m. mollis* populations from potential damage caused by trampling.

Southampton Marsh contains the only known population of *Spartina patens* in the San Francisco Estuary. Several large clones are scattered throughout the southern and western portions of the marsh, and multiple smaller clones are peppered throughout the area. A number of *S. patens* clones are adjacent to the main channel draining the marsh. There was a total of roughly 0.5 acre of *S. patens* at this site in 2005, which has reduced by herbicide applications in the areas that are not contiguous with *Cordylanthus*.. Some of the areas occupied by *S. patens* are directly adjacent to, or interspersed with individuals or patches of *Cordylanthus*. These areas are highly sensitive, and any *S. patens* eradication effort here will require diligent protection efforts for the *C. m. mollis*. The primary treatment method at this site is aquatic herbicide, which will be applied by backpack sprayer. The partner on this site is the California Department of Parks and Recreation.

Site 12 – Southeast San Francisco, San Francisco County

The Southeast San Francisco complex includes a scattered group of remnant marshlands totaling 56.7 acres within a heavily industrialized landscape on the western shores of the San Francisco Bay Estuary. The complex is bounded by the Islais Creek Channel and Pier 94 on the north, and the San Francisco County and City boundaries to the south. The Southeast San Francisco complex is adjacent to an inactive naval shipyard, shipping container facilities, and 3Com Park stadium (formerly Candlestick Park), as well as the Bayview residential neighborhood of San Francisco. Within this area there are a number of marshland habitats including intertidal mudflats, native *Spartina foliosa* stands, riprap shoreline, marshland fill, and pickleweed-dominated tidal marsh plain.

The six sub-areas of the Southeast San Francisco complex contained approximately 8.2 acres of *Spartina alterniflora* hybrids in 2005. This represents 14.5% of the area of these fragmented remnant marshlands. The rapid hybridization of this population, and conversion of these last pieces of remnant marsh in the area, lends a sense of urgency to the control efforts outlined in this plan. The individual patches of non-native *Spartina* within this area represent localized 'stepping stones' in the available marsh habitat of the area to the open waters of the North Bay, and the outer coast. Treatment occurred at most of these sites in 2005 & 2006, reducing the area to approximately 3 acres needing treatment in 2007. The treatment methods at this site include a combination of manual digging, covering with geotextile fabric, and application of aquatic herbicide by conventional spray truck. Partners on this site include the California Department of Parks and Recreation, Literacy for Environmental Justice (LEJ), Port of San Francisco, Golden Gate Audubon, City of San Francisco Recreation & Parks, and the U. S. Navy. Note that this is a complex site composed of multiple sub-areas. Please refer to the Site Specific Plan for detailed descriptions of the sub-areas and the associated treatment methods.

Site 13 – Whale's Tail / Old Alameda Creek Complex, Alameda County

The Whale's Tail and Old Alameda Creek Complex is a 564-acre site on the eastern shores of the San Francisco Bay Estuary, south of the San Mateo Bridge and bordered to the east by Union City. This area includes remnant marshland patches that predate alterations to the site for salt production, channelized flood control structures, restored salt pond marshland, small sinuous channels, high marsh flats, mudflats, eroding scarp, sand/shell beach, small depositional deltas, and other habitats. The areas included within this complex are entirely restricted from public access and are either managed by California Department of Fish and Game (CDFG) as wildlife habitat (Sub-Areas 13d, 13e, 13f), or by Alameda County Flood Control District for flood control purposes (Sub-Areas 13a, 13b, 13c, 13g). On the northern side of the main channel, formerly diked salt ponds are undergoing restoration activities to convert them to tidally influenced marshlands. To the south of the main channel, Cargill Corporation maintains active salt-producing evaporator ponds.

The invasive *Spartina* at the Whale's Tail and Old Alameda Creek Complex is one of the oldest infestations of non-native cordgrass in the San Francisco Estuary. The marshlands of this site contained a total of 82 acres of *Spartina alterniflora* hybrids representing 14.5% of the area. Applications in 2005 & 2006 were very effective, reducing the area to be treated in 2007 to less than 10 scattered acres, mostly in channels and other low elevation areas. The infestations are establishing in a wide variety of marsh habitats including high marsh pickleweed (*Salicornia virginica*)/saltgrass (*Distichlis spicata*), lower marsh *Spartina foliosa*/mudflat areas, channel banks, edges of salt pans, and bayfront scarps and mudflats.

Since the Cargill Mitigation Marsh was a former salt evaporator pond, it was largely unvegetated with native salt marsh species when tidal action was partially restored in 1995. Without any biotic resistance to invasion, the marsh has become infested with large, coalescing clones of invasive *Spartina*. On the eastern portion of the site, these clones have coalesced into meadows. The Cargill Mitigation Marsh sub-area contained approximately 19.0 acres of *S. alterniflora* hybrids, representing 38.8% of this restoration site in 2005. Treatment over the past two years has reduced the infestation substantially, with only several thousand square feet left to treat in 2007.

The primary treatment method at this site is aquatic herbicide, which will be applied by helicopter, with some follow up with tracked amphibious vehicle if necessary. Partners on this site include the Alameda County Flood Control District, California Department of Fish and Game, and the California Wildlife Foundation. Note that this is a complex site composed of multiple sub-areas. Please refer to the Site Specific Plan for detailed descriptions of the sub-areas and the associated treatment methods.

Site 15 – South San Francisco Bay Marshes, Santa Clara County

The South Bay Marshes are located at the extreme southern tip of the San Francisco Bay, with both San Mateo and Alameda Counties bordering to the northwest and northeast, respectively. The area includes over 100 miles of shoreline, and encompasses some 1,750 acres of marshland. This highly diverse area includes extensive current and former salt ponds, restoration marshes, creek channels and sloughs, bay fill, large intact salt marshes, brackish marsh areas, slough edge marshes, pans, islands, mudflats, sand/shell beaches and other marsh habitats. Included within this area are Guadalupe Slough, Coyote Creek, Alviso Slough, Mountain View Slough and San Francisquito Creek. There is a high degree of complexity in the South Bay Marshes that will be enhanced significantly by the work of the South Bay Salt Ponds Restoration Project, which will convert sizable portions of former salt-making ponds to various types of marsh habitat.

The entire site is comprised of 145 individual patches of *S. alterniflora*/ hybrids ranging in size from 4 ft^2 to 17,000 ft^2, with a total infestation of roughly 8.0 acres. However it had expanded rapidly over the past several years, largely due to the ineffectiveness of glyphosate. Imazapyr has been able to reduce the infestation significantly, probably to just over 1 acre scattered throughout the area. The majority of the infestation occurs along the bayfront adjacent to the DENWR newly acquired ‘salt ponds’ A1 and A2W. Both Pond A1 and A2W marshes are composed of large expanses of intact native *Spartina foliosa* (California cordgrass) and pickleweed (*Salicornia virginica*), interspersed with gumplant (*Grindelia stricta*) and tule (*Scirpus* sp.) Both marshes lie adjacent to compacted earthen levee roads, which are gated, locked, and require DENWR permission to access. The other sites are patchy and scattered throughout the South Bay extending from San Francisquito Creek in the northwest to the Coyote Slough tidelands in the northeast. The primary treatment method at this site is aquatic herbicide, which will be applied by conventional spray truck, backpack sprayer, and boat. Partners on this site include the Santa Clara Valley Water District and the U.S. Fish and Wildlife Service, Don Edwards National Wildlife Refuge.

Site 16 – Cooley Landing, San Mateo County

Cooley Landing is a 165-acre salt marsh restoration site located at the northwestern point of the South San Francisco Bay Estuary, south of the Dumbarton Bridge and adjacent to the point where the Hetch-Hetchy Aqueduct makes landfall on the western shore at Menlo Park. The site is a former salt production evaporator pond that is undergoing restoration to tidal marsh. Initial restoration activities were completed between September and December of 2000, and included the excavation of two breaches through the east levee at locations of historic tidal channels. Re-vegetation of the former salt pond is expected to occur through natural colonization. Performance criteria for the restoration of Cooley Landing requires 70 percent cover of salt marsh vegetation and less than five percent cover of non-native vegetation by the tenth year following restoration. Cooley Landing is part of the Ravenswood Open Space Preserve.

Prior to opening Cooley Landing to tidal action in 2000, just five adult clones of invasive *Spartina* covering a total of 0.1 acre were present along the levees outboard of the restoration area. However, since *S. alterniflora* hybrids are known to occur on the adjacent properties north and south of the restoration area, and restored salt ponds lack the biotic resistance in the form of an established native plant community, the infestation spread rapidly and already covered 20.0 acres of the restoration site or 13 % of this large area by 2005. Treatment in 2006 over a portion of the site has reduced the infestation by 50%. The primary treatment method at this site is aquatic herbicide, which will be applied by helicopter with some follow-up with backpacks, Argos, or conventional spray truck possible. Partners on this site include S.S. Papadopoulos Associates and the Midpeninsula Regional Open Space District, as well as San Mateo County Mosquito Abatement District.

Site 17 – Alameda Island / San Leandro Bay Complex, Alameda County

The area encompassed by this Site-Specific Plan includes all marshlands of the Alameda and San Leandro Bay Area extending from the western tip of Bayfarm Island and San Leandro Channel in the west, to east of Interstate 880 and the Oakland Coliseum in the east. The northern boundary of the site is the Port of Oakland shipping terminals, and the southern edge is 98th Ave on San Leandro Creek. This area supports many diverse habitat types despite the fact that it is directly adjacent to some of the most highly developed land on the west coast. Within this area there are recently restored tidal marshes, freshwater ponds and upland islands, highly complex and diverse historic marsh habitats that include channels, high marsh, mudflats and pans, thin strip marshes along rip-rapped shoreline, public parks and trails, open mudflats, creek channels and mouths, sandy beach areas, marinas, private residences, commercial areas, industrial manufacturing facilities, shipping, and many other land use types.

The *Spartina* infestations within this site are distributed throughout the habitat types described above. Most notably, Arrowhead Marsh and the Elsie Roemer Bird Sanctuary support the largest infestations of *Spartina* in the Alameda and San Leandro Bay Complex. In sum, the shoreline of this site contained 88.5 acres of non-native *Spartina* in 2005 targeted for control. This infestation was rapidly expanding into new areas, including the restored marshlands of the Martin Luther King Jr. Wetlands Project. Treatment in

2005 & 2006 has reduced this infestation to approximately 35 acres. The primary treatment method at this site complex is aquatic herbicide, which will be applied by conventional spray truck, backpack sprayer, amphibious tracked vehicle, boat, and helicopter. Some private landowners may choose to use manual digging or covering with geotextile fabric to control small infestations on their land. Partners on this site include the Alameda County Flood Control District, East Bay Regional Parks District, City of Alameda, City of Oakland, Port of Oakland, U.S. Coast Guard, Save the Bay, and Golden Gate Audubon. Note that this is a complex site composed of multiple sub-areas. Please refer to the Site Specific Plan for detailed descriptions of the sub-areas and the associated treatment methods.

Site 18 – Colma Creek / San Bruno Marsh Complex, San Mateo County

The areas encompassed within this Site-Specific plan includes all of the marshlands north of the San Francisco International Airport, up to the northern tip of the outlet of San Bruno Canal or Colma Creek. Within this area there are broad marshlands fringing the industrial fill of South San Francisco, channel bank marshland habitat, open mudflats, pickleweed and gumplant marshes, upland marsh edges, brackish creek channels and other tidal marsh systems. Much of this area is highly developed with light industrial, commercial, and business facilities, and a portion of the Bay Trail runs through the northern portion of the site. For the purposes of this plan, there were an estimated 100.3 acres of marshland within this site in 2005.

The *Spartina* infestations within this site are distributed throughout the habitat types described above. In sum, the marshes of this site contain 60.0 acres of non-native *Spartina* targeted for control, representing 60% of the surrounding marsh. This infestation has rapidly expanded onto the open mudflats on the western portion of this site, as well as constricting the channels on the northern and southern portions. Non-native *Spartina* has dominated most of the available marshland habitat, with only scattered populations of native tidal marsh plant species remaining in the area. Because of the unusually large and high density population of clapper rail in this site complex, treatment has been phased over several years, with only the upper channels receiving applications in 2006. Most of the area will be treated in 2007, although some will simply be “chemically mowed” to stop seed production while maintaining the above-ground biomass for rail refugia. The primary treatment method at this site is aquatic herbicide, which will be applied by conventional spray truck, backpack sprayer, amphibious tracked vehicle, and/or helicopter. Partners on this site include the San Mateo County Mosquito Abatement District, San Mateo Flood Control District, City of South San Francisco, and the San Mateo County Transit District (Sam Trans). Note that this is a complex site composed of multiple sub-areas. Please refer to the Site Specific Plan for detailed descriptions of the sub-areas and the associated treatment methods.

Site 19 – West San Francisco Bay, San Mateo County

The area encompassed by this Site Specific Plan includes all marshlands of San Mateo County extending south from the San Francisco/San Mateo County line in the north to the San Mateo-Hayward Bridge in the South. A separate Site-Specific Plan for the Colma Creek/San Bruno Marsh Complex (TSN:ISP-2005-18) has been developed to specifically address the *Spartina* treatment approaches for that area, and is therefore not included in this plan. Many of the Sub-Areas for this site are small marshes or mudflat areas bordered by light or heavy industrial development, riprap shoreline, Highway 101, the San Francisco International Airport, or other intensive uses. Several are partially restored marshes. Few of these Sub-Areas support diverse, intact native marsh conditions, and non-native *Spartina* has come to dominate each one.

The infestations of non-native *Spartina* that constitute the West San Francisco Bay Complex are scattered along the shoreline in many types of habitats. *Spartina* can be found along the rip-rap of shoreline development, in remnant or newly formed pickleweed marsh, along channels emptying into the bay, amongst sand/shell beaches, within large established marsh, in wide lagoons, on shallow mudflats, and in small coves and sheltered crannies all along the Bay edge. In all Sub-Areas, non-native *Spartina* is rapidly expanding into the existing available habitat. Out of an estimated 350 acres of marsh habitat covered by this Site-Specific Plan, there were 85 net acres (24%) of non-native *Spartina* requiring control in 2005. Two years of successful treatment by SMCMAD has reduced this site complex to less than 10 widely scattered acres. The primary treatment method at this site is aquatic herbicide, which will be applied by conventional spray truck, backpack sprayer, amphibious tracked vehicle, boat, and helicopter. Partners on this site include the San Mateo County Mosquito Abatement District, San Francisco International Airport, Oyster Point Marina, City of Brisbane, City of Burlingame, City of San Mateo, County of San Mateo, City of Foster City, California State Lands Commission, Universal Paragon Corporation, San Bruno Mountain Watch, City of South San Francisco, U.S. Coast Guard Reservation, San Mateo County Harbor District and a number of individual commercial property owners. Note that this is a complex site composed of multiple sub-areas. Please refer to the Site Specific Plan for detailed descriptions of the sub-areas and the associated treatment methods.

Site 20 – San Leandro / Hayward Shoreline Complex, Alameda County

The area encompassed by this Site-Specific Plan includes the marshlands of the San Leandro and Hayward shoreline, Alameda County, extending south from the Metropolitan Golf Course and Oakland International Airport in the north to the San Mateo-Hayward Bridge in the south. A separate Site-Specific Plan for Oro Loma Marsh (TSN:ISP-2004-07) has been developed to specifically address the *Spartina* treatment approaches for that area, and is therefore not included in this Plan. The marshland areas in this site complex range from large, complex restored marsh systems to channel-bank fringe marsh areas. They line the east shore of the Bay, providing a natural border between the highly urbanized and developed areas of the cities of San Leandro, San Lorenzo, and Hayward and the open waters of the Bay. Much of this area is regularly used for passive recreational activities along portions of the Bay trail, within EBRPD lands, and other trails throughout the area.

The infestations of non-native *Spartina* that constitute the San Leandro and Hayward Shoreline Complex are located along the shoreline in many types of habitats. Invasive *Spartina* can be found along the rip-rap of shoreline fill and levees, in remnant or newly formed pickleweed marsh, along channels emptying into the bay, amongst sand/shell beaches, within large established marsh restoration sites, on shallow Bay-edge mudflats, and in small coves and sheltered marsh areas along the Bay edge. In all sub-areas, non-native *Spartina* was rapidly expanding into the existing available habitat. Out of an estimated 580 acres of marsh habitat covered by the Site-Specific Plan, there were an estimated 204 net acres of non-native *Spartina* requiring control in 2005, representing 35.2% of the area. Treatment in 2006 has reduced this infestation by 60-70%, leaving approximately 50-60 acres to treat in 2007. The primary treatment method at this site is aquatic herbicide, which will be applied by helicopter, conventional spray truck, backpack sprayer, and amphibious tracked vehicle. Partners on this site include the Alameda County Flood Control District, East Bay Regional Parks District, City of San Leandro, City of Oakland, and the Oro Loma Sanitary District. Note that this is a complex site composed of multiple sub-areas. Please refer to the Site Specific Plan for detailed descriptions of the sub-areas and the associated treatment methods.

Site 21 – Ideal Marsh, Alameda County

Ideal Marsh is a 178.8-acre wetland restoration site located on the eastern shore of the San Francisco Bay Estuary that was allowed to naturally restore to unrestricted daily tidal exchange. The site is bordered to the north by the mouth of the Alameda Flood Control Channel (TSN:ISP-2004-1); the shoreline marshes of this site run for approximately 2.5 miles south of the channel to a point about a mile north of the Dumbarton Bridge where a levee cuts back to the shoreline. Levees along the eastern edge of this site separate it from current salt evaporator ponds, with the Coyote Hills, and the Regional Park of the same name, located just over one mile to the east.

The two Sub-Areas of Ideal Marsh (North and South) were being rapidly colonized with an expanding infestation of *Spartina alterniflora* hybrids, with a total of 98 acres of invasive *Spartina* or 54% of the marshlands at Ideal Marsh in 2006. These plants occupy all habitat types present in these marshes, including open mudflats, sand/shell beaches, eroding marsh edge, pickleweed plain, levee edge and other areas. The area to be treated in 2007 was greatly reduced by the highly effective applications in 2005 & 2006, with approximately 2-3 acres remaining. The primary treatment method at this site is aquatic herbicide, which will be applied by helicopter. The partner on this site is the U.S. Fish and Wildlife Service, Don Edwards National Wildlife Refuge.

Site 22 – Two Points Complex, Alameda County

The Two Points Complex is located on the east side of north San Francisco Bay and southeast San Pablo Bay in Contra Costa County, along the shoreline of the City of Richmond, and includes areas both north and south of the Point Richmond peninsula and the Richmond-San Rafael Bridge. The shoreline adjacent to these sites is heavily developed with land use including commercial, industrial, residential, and park or marina areas. The Bay Trail provides recreational access along the upland edge of the southern marshes in the complex, but only provides distant viewing of the north marshes because the trail is located further inland at this point. The marshes of this area are wide fringing marshes with mixed pickleweed/*Spartina* vegetation assemblages. These marshes contain large and small channels, mudflats, wide mid-marsh plains and other areas.

The infestations at the Two Points Complex are still in the early stages of establishment, with approximately 5 acres scattered over the 598 acres of the five sub-areas, or less than 1% of the total marsh area. The establishing clonal patches within this area are located mostly along the bay front amongst native *Spartina* stands or along the banks of small channels within the marshes, and are beginning to coalesce. A few clones have begun to establish within the mid-marsh plain on some of the Sub-Areas as well. The primary treatment method at this site is aquatic herbicide. Partners on this site include the State of California Lands Commission, Cherokee Simeon Venture I, LLC, Republic Services, Chevron/Texaco, Bay Area Wetlands LLC, Richmond Rod and Gun Club Inc., and East

Bay Regional Parks District. Note that this is a complex site composed of multiple sub-areas. Please refer to the Site Specific Plan for detailed descriptions of the sub-areas and the associated treatment methods.

Site 23 – Marin Outliers, Marin County

The area encompassed by this Site Specific Plan includes selected marshlands of Marin County extending south from the Point San Pedro in the north to Sausalito in the South. Separate Site-Specific Plans for the Corte Madera Creek Complex (TSN:ISP-2005-04), Blackie's Pasture (TSN: ISP-2004-03) and Pickleweed Park (TSN:ISP-2004-09) have been developed to specifically address the *Spartina* treatment approaches for each of those areas. Many of the Sub Areas are small marshes or mudflat areas bordered by light or heavy industrial development, rip-rap shoreline, or other uses. Several are partially restored marshes. In sum, these areas represent an important patchwork of small marsh areas within Marin County.

The infestations of non-native *Spartina* that constitute the Marin Outliers complex are scattered along the shoreline in many types of habitats. *Spartina* can be found along the rip-rap of shoreline development, in remnant or newly formed pickleweed marsh, along channels emptying into the bay, within large established marsh, on shallow mudflats, and in small coves and sheltered crannies along the Bay edge. In all Sub-Areas, non-native *Spartina* was in the initial stages of expansion into the existing habitat. Out of an estimated 130 acres of marsh habitat covered by this Site-Specific Plan, there were 2.6 net acres of non-native *Spartina* requiring control in 2005, representing 2% of the marsh area. Most of these sites are down to several hundred square feet or less after effective treatments in 2005 and/or 2006. The primary treatment method at this site is aquatic herbicide, which will be applied by backpack sprayer, conventional spray truck, and by boat. Partners on this site include Cherokee Simeon Venture I, LLC, County of Marin, Loch Lomond Marina, Strawberry Recreation District, City of Mill Valley, California State Lands Commission, McNear Brick and Block, Paradise Cay Yacht Club, and a number of smaller residential and commercial landowners. Note that this is a complex site composed of multiple sub-areas. Please refer to the Site Specific Plan for detailed descriptions of the sub-areas and the associated treatment methods.

Site 24 – Petaluma River, Sonoma County

This area includes approximately 4,500 acres of marshland and riparian habitat within the Petaluma River Watershed stretching from the City of Petaluma, at the confluence of the Petaluma River and Lynch Creek in the north to San Pablo Bay in the south. This site consists of a complex mosaic of historic tidal marsh habitat, developed shoreline, brackish tidal riparian edge zones, maintained pastureland, restoration sites, light industrial facilities and urban development.

The pioneering infestation of *Spartina alterniflora* hybrids in the Petaluma River complex was discovered in November 2006, and is still very limited in its distribution. The majority of the infestation is located along the banks of the river adjacent to a dredging and barge dock facility just downstream of the Highway 101 crossing south of Petaluma, with scattered infestations located upstream and downstream this central core. In sum, these infestations cover approximately 0.2 acres scattered over this very large marshland complex, which is equal to less than 0.01% of the area. The primary treatment method at this site is aquatic herbicide, which will be applied by boat, backpack and/or conventional spray truck. The primary ISP partner on this site is the Friends of Petaluma River, a group that has existing relationships with the community of the watershed and the landowners along the river.

9. WATER QUALITY MONITORING PLAN

Objective

Conduct water quality monitoring sufficient to achieve compliance with NPDES State-wide General Permit requirements.

Site Selection

Approximately 138 sites (sub-areas) of invasive *Spartina* throughout the San Francisco Bay region are slated for treatment with aquatic herbicide during the 2007 control season. According to current NPDES permit requirements, ten percent (10%), or 14 of the 138 sites, must be monitored for water quality. These sites are to be selected at representative locations, and are to include all of the herbicides being applied. To assist with sampling site selection, the ISP identified four different treatment site types, as follows:

I. Tidal Marsh, Microtidal Marsh, Former Diked Bayland, Backbarrier Marsh

II. Fringing Tidal Marsh, Mudflats, and Estuarine Beaches

III. Major Tidal Slough, Creek or Flood Control Channel

IV. Urbanized Rock, Rip-Rap, Docks, Ramps, etc.

The ISP has selected a relatively even distribution of these marsh site types to be sampled for water quality. Type IV infestation sites are usually very small, sparse, and adjacent to large bodies of water with constant flushing that will serve to quickly dilute any herbicide incidentally entering the water column. Site Types I and II were previously considered to be the sites most likely to develop detectible levels of herbicide in the water column, so the 2005 and 2006 sampling programs were weighted in this direction. However, the results of ISP's 2006 WQMP revealed that the highest one-week post-treatment samples actually came from two Type III sites. For 2007, the final sampling plan list takes that finding into consideration, and includes four Type I sites, four Type II sites, four Type III sites, and two Type IV sites that were chosen to represent the range of herbicide delivery systems and marsh dynamics present in our work program. Imazapyr is the primary herbicide and glyphosate will only be applied to one of the 138 sub-areas, so we consequently plan to monitor just one glyphosate site for water quality as a representative. See Table 5 for a summary of the sites.

Site Descriptions

Following are brief descriptions for each of the monitoring sites. Additional site information was included previously in Section 8 of this plan.

Alameda Flood Control Channel. The Alameda County Flood Control Channel (ACFCC) is a large, unlined trapezoidal channel that runs from east to west through Hayward, Alameda County, draining a nearly 880 square mile watershed into the San Francisco Bay. The levees on both sides of the ACFCC are topped with multi-use public park trails that are part of the San Francisco Bay Trail and Coyote Hills Regional Park. The flood control channel will be sampled right at its mouth to the San Francisco Bay, a

Type II site. Efficacy from 2006 imazapyr applications was high, and the site will be retreated where necessary in 2007.

Old Alameda Creek. The Old Alameda Creek South Bank sub-area, a Type III site, consists of 27.3 acres of marshland along the channel consisting of a 5-15 m wide bench grading from open mud and *S. foliosa* to pickleweed/gumplant higher marsh up to the levee edge. This area runs from the mouth of the channel upstream approximately 4 miles to the "20-Tide Gates" flood control structure near Union City. Efficacy from 2006 imazapyr applications was high, and the site will be retreated where necessary in 2007.

Creekside Park. This Type I site is estimated to contain 20.6 acres of marshland habitat adjacent to the upper portion of Corte Madera Creek just upstream of Bon Air Road. The park was restored to marshland habitat in 1976, when a new channel system was excavated, upland areas were graded to intertidal elevations, and central islands were constructed from the channel dredge spoils as upland refugia. As part of this initial restoration effort, both *Spartina densiflora* and *Spartina anglica* were planted, as native marsh plants failed to establish within the first year of restoration. These plants were imported from Humboldt Bay and England respectively. Efficacy from 2006 imazapyr applications was high, and the site will be retreated where necessary in 2007.

Colma Creek Complex. Two sites in the Colma Creek Complex will be monitored, the shoreline of Sam Trans Peninsula and the entirety of Inner Harbor.

Table 5. Summary of Water Quality Monitoring Sites for the 2007 Season

Sites	*Site Number*	*Marsh Type*	*Treatment Date*	*Application*
Riviera Circle	4f	IV	7/16/07	Imazapyr – Boat
Martin Luther King Jr. Shoreline (Damon Marsh)	17d	II	7/30/07	Imazapyr – Helicopter
Alameda Flood Control Channel Mouth	1a	II	7/31/07	Imazapyr – Helicopter
Old Alameda Creek South Channel	13c	III	8/1/07	Imazapyr – Helicopter
Inner Harbor	18d	II	8/1/07	Imazapyr – Helicopter
Sam Trans Peninsula	18e	II	8/1/07	Imazapyr – Helicopter
San Mateo Creek/Ryder Park	19o	III	Early August	Imazapyr – Argo
Oakland Inner Harbor	17f	IV	8/13/07	Imazapyr – Boat
Creekside Park	4g	IV	9/11/07	Imazapyr – Backpack
Elsie Roemer Bird Sanctuary	17a	II	9/11/07	Imazapyr – Truck, Backpack
Citation Marsh	20d	I	9/11 to 9/14/07	Imazapyr – Truck
Mills Creek Mouth	19i	II	9/11 to 9/14/07	Imazapyr – Argo, Truck
Fan Marsh	17j	I	9/11 to 9/14/07	Imazapyr – Truck
Southampton Marsh	11	I	Late September	Glyphosate – Backpack

Sam Trans Peninsula. The Sam Trans Peninsula is a reclaimed peninsula constructed of fill to the north of the San Francisco International Airport. This site contains the fringing marsh areas on the east side of the peninsula proper, from the North Access Road north, to just west of the tip of the peninsula. Within this area there is an estimated 14.1 acres of marshland habitat with an estimated 8.0 acres of non-native *Spartina*. The *Spartina* is growing on previously open mudflats in mostly uniform monocultural stands, and advancing eastward into the Bay. This Type II site will be treated for the first time in 2007.

Inner Harbor. The invasive *Spartina* has caused this marsh to establish through the accretion of sediment on the open mudflats west of the Sam Trans Peninsula. San Bruno Creek feeds this area of the complex from its mouth in the southwest corner of Inner Harbor. This sub-area encompasses some 14.6 total acres of marshland, mudflat, and channel. The *Spartina* here consists of a coalesced meadow in the south and expanding individual pioneer clones scattered through the northern area. In sum, the infestation at this site is estimated at 8.5 acres. This site will be treated for the first time in 2007.

West San Francisco Bay Region. The area encompassed by the West San Francisco Bay Region includes all marshlands of San Mateo County extending south from the San Francisco/San Mateo County line in the north to the San Mateo-Hayward Bridge in the south. Excluding the Colma Creek Complex, there are 18 Sub-Areas in this area. Several are partially restored marshes or creek mouths and their mudflats were infested with expanding populations of invasive *Spartina*. Others are small marshes or mudflat areas bordered by light or heavy industrial development, rip-rap shoreline, Highway 101, the San Francisco International Airport, or other intensive uses. The sites from this complex selected by ISP for water quality monitoring include San Mateo Creek/Ryder Park and Mills Creek Mouth.

San Mateo Creek/Ryder Park. This Type III site consists of 6.3 acres including the San Mateo Creek Channel, the small portion of marsh around the creek mouth, and the coalescing *Spartina* on the mudflat. It is adjacent to and within the newly developed Ryder Park in the City of San Mateo. Efficacy from 2006 imazapyr applications was high within in the channel but not on the mudflats, and the site will be retreated where necessary in 2007.

Mills Creek Mouth. The Mills Creek Mouth sub-area is a 6.5-acre area of marsh within the boundaries of the City of Burlingame located to the east of Hwy 101 and the Bayshore Highway. Within this area, the outlet of the creek forms a small delta bound by commercial development. Along the stretch of creek above Bayshore Highway there are scattered stands of *Spartina* lining the channel. The bulk of the infestation is in the mouth of the channel, east of the Bayshore Highway. The marsh in this small delta is dominated by non-native *Spartina,* with several large clones establishing on the outer mudflats beyond the channel mouth. The estimated acreage for this infestation is 3-4 acres. This Type II site will be treated for the first time in 2007.

Alameda-San Leandro Bay. Three sites in the Alameda-San Leandro Bay complex will be monitored, Elsie Roemer Bird Sanctuary, Damon Marsh along the Martin Luther King Jr. Shoreline, and Fan Marsh.

Elsie Roemer Bird Sanctuary. This Type II site includes an area along a stretch of southern Alameda Island, which runs from the jetty off Shoreline Dr. in the west to the Bayfarm Island Bridge in the east. Within the estimated 17.3 acres of marsh at this site, there are approximately 7 acres of non-native *Spartina alterniflora* hybrids, including several large clones coalescing on the open mudflats south of the main infestation. Efficacy from 2006 imazapyr applications was moderate, and the site will be retreated where necessary in 2007.

Martin Luther King Jr. Shoreline (Damon Marsh). The Martin Luther King Regional Shoreline runs along the eastern portion of San Leandro Bay from Arrowhead Marsh in the south to the northern side of the outlet of the East Creek Channel, which drains both Peralta and Seminary Creeks in Oakland. This area includes the large, heavily-infested marsh between East Creek and Damon Slough called Damon Marsh, which is a wide pickleweed/*Spartina* marsh with an upland edge that borders the adjacent trail. Fringe marsh runs along a rip-rap shoreline from East Creek Mouth to Damon Marsh. In some cases within this Sub-Area, non-native *Spartina* has developed marsh areas that were previously only open water or mudflat and rip-rap fill edges. Efficacy from 2006 imazapyr applications was excellent over most of the site but relatively poor at lower elevation, and this Type II site will be retreated where necessary in 2007.

Fan Marsh. Fan Marsh is a roughly 11-acre marsh located along on the interior of Doolittle Drive at Earhart Road in Alameda. The property is owned by the Port of Oakland and consists of high marsh pickleweed/*Spartina* interspersed with several small channels draining to the Bay to the east of Doolittle Pond (sub -area 17l). The *Spartina* infestation within Fan Marsh is fairly uniform over the entirety of the marsh area. Roughly 5 acres of *Spartina* are spread over 11 acres of channels and high marsh plain at this site. This Type I site will be treated for the first time in 2007.

Oakland Inner Harbor. This sub-area consists of all the small areas of marsh within the Oakland Inner Harbor, including lands along the City of Alameda's northeastern shoreline as well as the City of Oakland's southwestern shore. Non-native *Spartina* within this sub-area is scattered throughout a complex matrix of industrial, commercial and residential land uses. The individual clones that have established in this area are typically quite small, establishing in rip-rap or steep fill edges, under or around docks or piers, and along sea walls or other similar locations. Within the estimated 100 acres of shoreline habitat along both the Alameda and Oakland portions of this sub-area, there is an estimated 6.5 total acres of *Spartina* requiring control. This Type IV site will be treated for the first time in 2007.

Southampton Marsh. Southampton Marsh is the largest extant marsh within the Carquinez Strait. Its roughly 175 acres are located within the 720-acre Benicia State Recreation Area, Solano County. The Marsh lies in the central portion of the park, and consists mostly of high marsh pickleweed/gumplant habitat, with a deep main channel and several smaller channels throughout. *Cordylanthus mollis* ssp. *mollis* (soft bird's-beak), an endangered plant species, can be found in some of the high marsh areas of the site. Access to the marsh is restricted to park personnel and researchers to protect the *C. m. mollis* populations from potential damage caused by trampling. Southampton Marsh contains the only known population of *Spartina patens* in the San Francisco Estuary. Several large clones are scattered throughout the southern and western portions of the marsh, and multiple smaller clones are peppered throughout the area. A number of *S. patens* clones are adjacent to the main channel draining the marsh. This is a Type I site and will be the only monitored site treated with glyphosate in 2007.

Citation Marsh. Citation Marsh is a large restored marsh adjacent to the residential development in the City of San Leandro. This marsh is estimated at 112 acres of mixed pickleweed habitat, constructed channels, open mudflat, pans, scattered upland areas, old levee systems and ponded areas. There is a high degree of establishing complexity to this marsh, and its tidal prism is somewhat damped by the fact that it is located inland of several other formerly diked restoration marshes. Within this large marsh area some 10 acres of non-native *Spartina* hybrids have established. The plants are scattered throughout the marsh, with some concentrated areas on the lower elevations in the northwestern portion of the site, and along the larger channels along the western portion of the site that drain this marsh to the Bay. Efficacy from 2006 imazapyr applications over a portion of the site was high, and the entire Type I site will be treated/retreated where necessary in 2007.

Sampling Frequency and Sampling Design

The sampling events are designed to characterize the potential risk involved with imazapyr and glyphosate applications relative to adjacent surface waters. Consistent with permit requirements, the monitoring program will include background/pre-treatment sampling up to 24 hours prior to the application, application event monitoring immediately post-treatment, and one-week post-application event monitoring. During background sample collection, the point will be recorded using GPS and marked with a flagged PVC pipe to aid ISP staff in locating the point for future sampling events. The application event samples will be collected immediately adjacent to the treatment area after sufficient time has elapsed such that treated water will have entered the adjacent area. Since it is standard protocol for the ISP partners to treat *Spartina* on a low or receding tide when possible, application event samples will often be taken 2-5 hours post-treatment when the tide has again flooded the site. Finally, the one-week post-treatment monitoring will be conducted when sufficient water is present at the site on the seventh day after the application. The Water Pollution Control Laboratory recommends the submission of one duplicate for every 20 samples collected, so the ISP will be submitting three duplicates for the 42 total samples taken to enhance quality assurance. These will be added to either the treatment event or one-week post-treatment event since the herbicide levels in the pre-treatment samples are usually 0. It is standard for the lab to include blanks itself as part of their quality control, so the ISP will not be sending additional blanks.

Sampling Procedures

The *Spartina* Project will be conducting its own water quality monitoring program for 2007 following the procedures developed for the State Water Resources Control Board Aquatic Pesticide Monitoring Program (APMP) by the San Francisco Estuary Institute (SFEI). These procedures are outlined in the APMP Quality Assurance Program Plan (2004), available at www.sfei.org. Water samples will be collected using a sampling rod and pre-cleaned amber glass 1-liter bottles. Temperature, electrical conductivity, salinity, and dissolved oxygen will be measured in the field with a portable YSI Model 85 (Yellow Springs Instruments Inc., Ohio, USA), while pH will be measured with an Oakton waterproof pHTestr1 (Oakton Instruments, Illinois, USA). Turbidity will be measured by the lab from the water samples submitted by ISP, as allowed for in the NPDES Statewide General Permit.

Sample Analysis

Following collection, water samples will be stored on ice packs and shipped for overnight delivery to the California Department of Fish and Game's Water Pollution Control Laboratory in Rancho Cordova, CA. The samples will be analyzed within the appropriate holding times for imazapyr or glyphosate concentrations. The analytical lab will adhere to all QA requirements outlined in the APMP QA plan.

Data Analysis

The results of the conventional water quality parameters (turbidity, water temperature, dissolved oxygen, pH, conductivity, and salinity) will be tested for normality and then analyzed with paired t-tests to determine if the values of the parameters change significantly over the three sampling events at each site. This test is used for matched pairs when two responses form a pair of measurements coming from the same experimental subject, such as measurement of dissolved oxygen before and after herbicide treatment in the adjacent marsh. The t-test will be run three times on each parameter, first comparing the pre-treatment value to the treatment value, then the pre-treatment to the post-treatment, and finally the treatment to post-treatment. Results will be submitted to the San Francisco Bay Regional Water Quality Control Board and placed on the ISP's website for public viewing.

10. APPLICABLE WATER QUALITY BMPS

The following mitigations were identified in the *Spartina* Control Program's Programmatic Environmental Impact Report/Statement (PEIR/S). These mitigations will be implemented at all herbicide treatment sites and verified by the Field Operations Staff.

IMPACT WQ-1: Degradation of Water Quality Due to Herbicide Application

MITIGATION WQ-1: Herbicides shall be applied directly to plants and at low or receding tide to minimize the potential application of herbicide directly on the water surface, as well as to ensure proper dry times before tidal inundation. Herbicides shall be applied by a certified applicator and in accordance with application guidelines and the manufacturer label.

The Control Program shall obtain coverage under the State NPDES Permit for the Use of Aquatic Herbicides and any necessary local permits. A monitoring program shall be implemented as part of the NPDES permit, and shall include appropriate toxicological studies to determine toxicity levels of the herbicide solutions being used. The Control Program shall use adaptive management strategies to refine herbicide application methods to increase control effectiveness and reduce impacts.

IMPACT WQ-2: Herbicide Spills

MITIGATION WQ-2: Herbicides shall be applied by or under the direct supervision of trained, certified or licensed applicators. Storage of herbicides and adjuvants/surfactants on-site shall be allowed only in accordance with an approved spill prevention and containment plan; on-site mixing and filling operations shall be confined to areas appropriately bermed or otherwise protected to minimize spread or dispersion of spilled herbicide or surfactants into surface waters.

When containers of herbicide larger than the standard 2.5 gallon are used (such as the 15 gallon containers that are used by the helicopter contractors for aerial application), these containers must remain in the staging area(s) on a levee or other appropriate upland site. These larger containers will not be allowed into the marsh, and a spill response plan must be in place in the event of an accidental discharge, to ensure that herbicide does not reach the marsh or surface waters.

IMPACT WQ-3: Fuel or Petroleum Spills

MITIGATION WQ-3: Fueling operations or storage of petroleum products shall be maintained off-site, and a spill prevention and management plan shall be developed and implemented to contain and clean up spills. Transport vessels and vehicles, and other equipment (e.g., mowers, pumps, etc.) shall not be serviced or fueled in the field except under emergency conditions; hand-held gas-powered equipment shall be fueled in the field using precautions to minimize or avoid fuel spills within the marsh. Other, specific best management practices shall be specified as appropriate in project-specific Waste Discharge Requirements.

In addition to these water quality mitigation measures, each partner agency and its contractors are required to have an acceptable Site Safety and Materials Handling Plan (Appendix 3).

Applicator Calibration Training

During the first year of operation, ISP recognized that, even when partners exercised great care during herbicide application, there was still considerable variability in application rates. Because the rate of herbicide application is critical for protecting water quality and staying within the project budget, the ISP began providing annual "Applicator Calibration Training" for contractors and agency personnel in 2006. The training, which is authorized by California Department of Pesticide Regulation Continuing Education, provides partners with a hands-on opportunity to practice and fine tune application techniques. At each training, ISP staff discuss the importance of correct application, and a representative of the herbicide manufacturer, BASF, presents the manufacturer's recommendations of how to apply imazapyr (Habitat®) properly. The presentations are followed by field exercises where partners compete to be the most accurate applicator.

A major motivation for these annual trainings came from a study in Cornish and Burgin (2005) showing that applicators applying herbicide to a given plot size could vary by as much as ten times in the amount of product used and the time it took to spray the plot. In their first experiment, applicators treated a 20 X 0.5m strip ($10m^2$). Application times ranged from 24.3 to 112.7 seconds, equivalent to 2.7 – 12.6 hours for them to complete one acre. They used the equivalent of 34.2 – 160 gallons/acre of tank mix, or 0.34 – 1.6 gallons of product per acre. For our expensive imazapyr herbicide (about $275 per gallon) the range would be $92 – $432 per acre, and more than twice the maximum label rate of 0.75 gallons per acre.

Their second experiment showed even more alarming results. Using a smaller $1m^2$ test area for the applications, treatment times ranged from 4.5 – 45 seconds, the equivalent of spending 5 – 50.6 hours on each acre. They used the equivalent of 21.4 – 684 gallons/acre of tank mix, or 0.21 – 6.84 gallons of product per acre. If this were imazapyr, the cost range would be $57 - $1847 per acre for the herbicide alone (up to nine times the max label rate), and labor costs would be extremely high for those on the upper end of the time spectrum.

In addition to off-label applications, lack of FIFRA compliance, and higher costs, there are other problems with this variation between applicators. As the BASF representative noted, over-applications can actually reduce efficacy by washing the product off the plants, which emphasizes the importance of getting the application rates right. This may be especially true when using surfactants made from oils.

The hands-on portion of the ISP field training is an attempt to directly address some of these obvious problems, achieve some consistency across the many applicators working around the Estuary on this project, and reduce the amount of herbicide entering the environment while still eliminating the *Spartina* threat efficiently. We established $340 ft^2$ plots in the marsh (equivalent to 1/128 of an acre) and had the attendees spray the plots (with just water, no herbicide) utilizing a variety of equipment including backpack sprayers, conventional spray truck, and amphibious vehicle. Applicators were timed and then were asked to spray into a bucket for the same length of time at the same pressure as the application. The amount of water in the bucket was measured and recorded for each participant. Because the area of the plots was 1/128 of an acre, and there are 128 ounces in a gallon, the number of ounces sprayed into each bucket was equivalent to the number of gallons per acre they would have applied. The beauty of this exercise is that once the plots are set up, it requires *no math* to achieve your calibration, just a timer and a bucket. BASF distributes these simple calibration kits for free to ISP partners. The training attendees were able to get direct feedback on their application rates and to see how easy and beneficial calibration can be, and left the training with a simple kit and protocol to do so. And managers in attendance were able to see how the correct rates will affect the bottom line and help to manage the budget for *Spartina* control.

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