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

This plan addresses herbicide application activities undertaken by
the coalition of 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, but 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 tidelands. Among these threatening invaders are several species of salt marsh cordgrass (genus *Spartina*). In the 1970's, non-native cordgrasses were introduced to the Estuary and began to spread, slowly at first and then much more rapidly as their populations reached critical mass. Though valuable in their native settings, these introduced cordgrasses are highly aggressive in their new environment, and routinely become the dominant plant species in areas they invade.

One of the non-native cordgrass species, Atlantic smooth cordgrass (*Spartina alterniflora*), was rapidly spreading throughout the Estuary at the beginning of ISP's control efforts, 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*) threatened the ecological balance of the Estuary. Based on international studies of comparable cordgrass invasions, these hybrids were likely to eventually cause the extinction of native Pacific cordgrass, while choking tidal creeks, dominating newly restored tidal marshes, and displacing thousands of acres of existing shorebird habitat. Once established in this estuary, invasive cordgrasses are able to disperse on the tides to other estuaries along the California coast through seed and/or propagules dispersal. At the start of the baywide implementation of ISP's control program in 2005-2006, non-native invasive cordgrasses dominated approximately 1,500-2,000 acres (806 net acres) of the San Francisco Estuary in seven counties — on State, Federal, municipal, and private lands— and were 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 stakeholders, with the ultimate goal of eradicating non-native cordgrasses from the San Francisco Estuary. The geographic focus of the ISP includes the nearly 50,000 acres of tidally-influenced marshes, mudflats and brackish channels that comprise the estuarine shorelines of the nine Bay Area counties, including Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma Counties.

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 were likely to be replaced with dense, invasive cordgrass marsh, and much of the diverse native salt marsh vegetation replaced with nearly homogeneous stands of non-native cordgrass. This ecological conversion would have altered the structure and function of the Estuary, affecting fisheries, migratory shorebirds and waterfowl, marine mammals, endangered fish, wildlife, and plants, as well as tidal sediment transport and the rate, pattern, and magnitude of tidal flows. In addition, invasive cordgrasses would have impeded the plans of the South Bay Salt Pond Restoration Project to restore up to 15,100 acres of diked baylands to native tidal systems. 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 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 resident and migratory shorebirds and waterfowl, with more than one million shorebirds using the Estuary's mudflats and salt ponds during annual migration, and over half of the west coast’s migratory diving ducks making this estuary their winter home.

At elevations above mean sea level (in areas that have not been diked and removed from tidal action), are the Estuary's tidal salt 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 exists a tidal marsh plain dominated by low-growing, mostly perennial plants such as pickleweed (*Sarcocornia pacifica*), saltgrass (*Distichlis spicata*), and other salt-tolerant herbs. The tidal marsh plain may also be punctuated by salty shallow ponds (pans) harboring specially-adapted invertebrate species, and may be dissected by irregular tidal channels. The high marsh ecotone at the uppermost edge of the marsh supports an even greater diversity of plant species.

Many endemic plant and animal species, including some that are rare or endangered, 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. Over 90% of the Estuary’s tidal marshes have been destroyed to accommodate salt evaporator ponds as well as residential and commercial development. Most of the Estuary's rare species have narrow habitat requirements, and the health of their populations is normally sensitive to structural changes in their habitats - particularly the condition of the marsh vegetation. Degradation of a healthy, diverse native plant assemblage by a single dominant invader 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 natural processes at both a regional and local scale. Hydrologic relationships between the Pacific Ocean, the Estuary, and the many freshwater tributaries (including the Sacramen-to-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 and bays distributing nutrients, suspended solids, and also pollutants. The 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.

Sub-regional Conditions. The Suisun and North Bay sub-regions 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 sub-region 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 freshwater flow creates a local zone of brackish water in the otherwise saline tip of 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 average 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 denser saline 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).

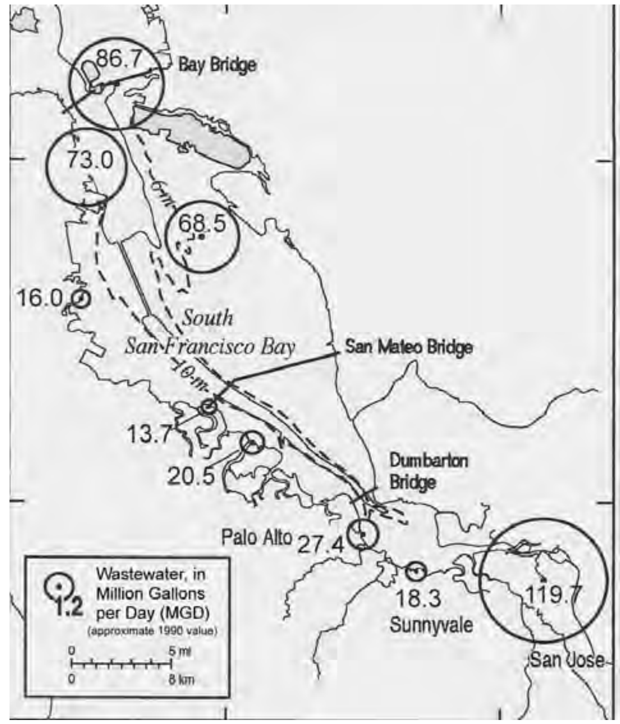

Figure 1. Locations and mean discharges for municipal wastewater treatment plants in South San Francisco Bay. Adapted from Schemel et al. 1999, based on Davis et al. 1991.

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 as an increasing percentage of the volume of water is tidal. At the mouth of the Sacramento River, for example, the mean annual salinity averages slightly less than 2 ppt, while 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 the 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). This salt water intrusion into the Delta is predicted to increase substantially with future sea level rise.

Dissolved Oxygen. Oxygen concentrations in estuarine waters are increased by the mixing action of wind, waves, and tides, the photosynthesis of phytoplankton and other aquatic plants, and high DO in freshwater inflow. DO concentrations are reduced 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). DO will also fluctuate with the tides and temperature such that shallow ponded areas at low tide in full UV exposure may be lower than the associated open water adjacent to the site.

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.

<u>Metals</u>. 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 pre-

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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.

sent 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.

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 of 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

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 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 sediments, 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

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

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 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. Pacific cordgrass (*S. foliosa*), the native species, is avoided during ISP's control efforts and is actually conserved 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)*. Both the non-native Atlantic smooth cordgrass and Chilean cordgrass hybridize with the native Pacific cordgrass, and their offspring (referred to as hybrid *S. alterniflora* or hybrid *S. densiflora*) are highly invasive. Key aspects of the cordgrass species found in the Estuary are contrasted below. The roles these species play in their native habitats give ecologists an indication of their potential to alter the salt marsh ecosystem of San Francicso Bay.

Native Pacific Cordgrass (*Spartina foliosa*)

The historic range of Pacific cordgrass was confined to estuaries from Point Reyes to Baja along the California coast, with large gaps in between (it was historically absent from Monterey Bay and Morro Bay). Most of the Pacific cordgrass population exists in San Francisco and San Pablo Bays, with its northern limit now being Bodega Bay, a small and recently-established 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 seldom exceed five feet in height including seed heads, 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, pollen and seed production, culm (stem) density 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 the mud substrate. 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"). Although pickleweed is generally the dominant plant of the marsh plain, which approaches the elevation of the MHHW in California estuaries, mature marshes often have short, low-density *S. foliosa* scattered amongst the pickleweed. The modest range in tidal elevation of Pacific cordgrass restricts the species to the sloping banks and benches of tidal creeks and the gently sloping upper elevation of mudflats. It is the marcrophyte that grows at the lowest elevation in the intertidal zone, leaving vast acreages of Pacific tidal flats below mean sea level entirely free of emergent vegetation in natural historic conditions.

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. However, the clapper rails generally use *S. foliosa* to construct their nest platforms.

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

Smooth cordgrass is a closely related sibling to Pacific cordgrass that is native to both the Atlantic and Gulf Coasts of the United States (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 introduced from Maryland in the mid-1970s in an experiment in dredge spoils stabilization for one of the first tidal marsh restoration projects on the West Coast.

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.), and have been witnessed by ISP biologists at restoration sites around the Estuary including Pond B3 (Middle Bair Island) and Cooley Landing.

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 eight 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). However, much of the variation in phenotype displayed around San Francisco Bay is also a result of multiple generations of backcrossing of the hybrids with *S. foliosa*.

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).

Atlantic smooth cordgrass is also highly resilient in regards to other environmental tolerances. It can survive in salinity over 45 parts per thousand (well above ocean salinity of 32 ppt), and grow luxuriantly in dilute brackish water. If buried, it can regenerate from up to one foot of burial by deposited sediment. Atlantic smooth cordgrass, like other wetland species, can supply oxygen to its roots in anoxic, waterlogged mud, by using porous air-filled chambers (aerenchyma) 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 were frequent, 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 role 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. After numerous clones of the invader develop, they eventually coalesce into single-species meadows that exclude native marsh vegetation and alter the ecology for the animals that depend on these systems for habitat. The edges of the colonies are tall and robust, while the centers often exhibit early symptoms of die-back or "short form" growth habits. The "donut" shape of colonies 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 genetically 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 don’t normally overlap, 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 (up to 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 (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 that were presumed to be Atlantic smooth cordgrass in the Estuary were predominantly hybrids and back-crosses (introgressants). The ecologically invasive 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 would 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.

Hybrid *S. alterniflora* was well established and widely distributed in the Central and South Bay at the start of ISP's control program, but its was detected early and controlled by ISP in the North Bay (and have not yet been detected in Suisun, despite intensive surveys). The northern limit of its distribution in 2005 on the east bay was at Giant Marsh (Point Pinole), and on the west bay was a clone north of Miller Creek mouth (north of China Camp). Over the years there have been infestations detected on the Petaluma River, Sonoma Creek, Mare Island, and a single clone at Sonoma Baylands. Pioneering infestations of hybrid *S. alterniflora* have also been managed at Drakes Estero, Limantour Estero and Bolinas Lagoon on the Point Reyes peninsula. The abundance of Atlantic smooth cordgrass and hybrids remains greatest in San Leandro Bay, Robert's Landing, and outer Bair Island, but has been reduced by 94% baywide by ISP partners since 2006.

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 along Corte Madera Creek in Marin County, along with Chilean cordgrass, in 1976. Unlike Atlantic smooth cordgrass and Chilean cordgrass, this species failed to disperse from its point of introduction to expand the infestation beyond Creekside Park. It may be at or near its southern climatic limit on the Pacific Coast in the 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 *Grindelia stricta* (gumplant) 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 oxygen from foliage to roots (Spicher 1984), a feature common to cordgrasses adapted to low marsh environments that can thereby withstand greater regular tidal inundation.

Chilean cordgrass, along with other South American coastal species, was 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 obvious lack of diagnostic traits matching this species. In the late 1970s, the presumed native "Humboldt Bay form" of Pacific cordgrass was deliberately transplanted to a salt marsh restoration at Creekside Park along Corte Madera Creek in Marin County. Within the salt marshes fringing Corte Madera Creek, it became 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 is very close to eradication. A population was also introduced (anonymously) to Sanchez Marsh along the West Bay in Burlingame, and more recently to a brackish drainage area in Redwood City. Both of these infestations did not spread to other marshes and are down to manual removal of a handful of plants each year until the seedbank is exhausted (which takes at least three years). 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 pioneering plant was quickly eradicated.

In 2007-2008, ISP biologists found a couple of instances of a new form of *S. densiflora*. It quickly became evident that this species had also successfully hybridized with native *S. foliosa* to produce a novel cordgrass. Within a year, ISP biologists found hybrid *S. densiflora* at many of the marshes in Marin where the two parents grew in close proximity. This “species” appears to spread vegetatively rather than by seed, but little is known about it and it has been actively treated since its discovery. If not for the vigilance of ISP, conducting annual monitoring at all the marshes of Marin and the rest of the Estuary, this invader would likely have gone undetected and uncontrolled, providing the opportunity for significant impacts to the ecosystem.

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 other 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. At the initiation of treatment by

ISP and State Parks, salt-meadow cordgrass at Southampton occupied large, discrete patches in pure and exceptionally thick stands compared with its native marshes. One large stand spread into an area that supports a population of an endangered annual plant, soft bird's-beak (*Cordylanthus mollis* ssp. *mollis* now *Chloropyron molle molle*). This overlap with an endangered plant have greatly complicated the final eradication efforts for *S. patens*. 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 documented 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 to a non-native stand capable of infesting adjacent marshlands.

Spartina densiflora has also been shown to have 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 marshlands have been dominated by it resulting in an infestation of 2000 acres by 2010. Fortunately, in the San Francisco Estuary we have only isolated populations of *S. densiflora* because of the efforts of the ISP and its partners, so as in the case with the more prevalent hybrid *S. alterniflora*, 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 inhabits only a single infestation site and in a relatively small remnant of the initial infestation in 2005. However, *S. anglica* is known 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 could be eradicated from the Estuary. The current Integrated Pest Management (IPM) strategy developed for *S. patens* relies completely on tarping the last stands and manual removal of the remaining individuals, so herbicide will no longer be required for this species.

6. DESCRIPTION OF HERBICIDE

Herbicides have proven highly effective in controlling populations of non-native cordgrasses (*Spartina* spp.). The aquatic formulation of imazapyr (Habitat® or Polaris™) was registered for use in the State of California on August 30, 2005. San Francisco Bay land managers that were engaged in their own independent *Spartina* control efforts prior to the inception of the ISP Control Program used aquatic glyphosate-based herbicides (Aquamaster®, Rodeo®). These the only two herbicide formulations registered by US EPA for use in sensitive estuarine systems; all ISP partners have since switched to imazapyr. Since imazapyr is such a slow-acting herbicide, it is often difficult to assess the efficacy of an application until the following spring.

There are a number of qualities that make imazapyr the ISP's preferred choice over the previous alternative, glyphosate. Glyphosate tends to strongly adsorb 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. 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 was essential to the ISP's initial efforts because of the vast acreage of *Spartina* infesting hazardous and difficult to access marshes at that time.

Aquatic herbicide formulations such as those used by ISP must be combined with a suitable surfactant to facilitate uptake by the plant 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® or Polaris™ are solutions 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 contain a small amount of an acidifier. Because Habitat® is purportedly a similar formulation as Arsenal® and this product contains acetic acid, the acidifier in Habitat® is likely also acetic acid (Leson & Associates 2005.) No information has been found in the published literature on manufacturing impurities associated with imazapyr. Because virtually no chemical synthesis yields a totally pure product, technical grade imazapyr most likely 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™.

Imazapyr inhibits an enzyme (acetolactate synthase [ALS]) 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, 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 lethal 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 that effect access to the marshes), 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 by the treatment.

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 the variability 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 maximizing herbicide distribution and forcing the fluid into the plant. As mentioned above, both Habitat® and Polaris™, 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 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 imazapyr deposition and uptake by the plants under moisture or temperature stress. Silicone-based surfactants, which reduce the surface tension of the spray droplet to an even greater degree, 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, especially in the heat of the summer, 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 also supported by Patten (2002) in which the author recommended using a methylated seed oil surfactant for aerial applications and for unfavorable conditions such as less than six hours of drying time before tidal inundation, or also on moist leaves. The experience of the ISP from since 2005 has shown that a lecithin (soybean) 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 high-pressure hose 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 imazapyr and glyphosate at the beginning of the Control Program in 2005. They include the non-ionic surfactants Liberate® and LI-700®, the crop-oil concentrate Agri-Dex®, the esterified seed oil Competitor®, and the organo-silicones Dyne-Amic® and Kinetic®. Based on the efficacy experienced by the ISP since 2005, and their superior relative toxicities to animals, the ISP expects to continue to exclusively use Competitor® and Liberate® in the *Spartina* Control Program. LI-700® may be used to balance the pH of the tank if/when glyphosate is employed. As of the 2012 Treatment Season, there are no glyphosate applications planned on invasive *Spartina* in the foreseeable future.

Cygnet Plus® was evaluated and originally included in the ISP 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.

Competitor (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 signal word).

Liberate (Loveland Industries, Inc.) is a non-ionic, low foam penetrating adjuvant. Its active ingredients are lecithin (phosphatidylcholine, which is a naturally occurring lipid derived from soybeans 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 signal word). It improves deposition and retards drift by producing a more uniform spray pattern.

Dyne-Amic (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 signal word).

Kinetic (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 especially 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 signal word).

Agri-Dex (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 signal word).[3]. Biodegradation of this adjuvant is presumed to be rapid.

LI-700 (Loveland Industries, Inc.) contains phosphatidylcholine (lecithin), which is a naturally occurring lipid derived from soybeans that biodegrades readily. It also contains methylacetic acid and alkyl polyoxyethylene ether. Toxicity studies classified this surfactant as a toxicity category of 1 (Danger signal word) 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 (MSDS) 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 triphenylmethane 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 during invasive *Spartina* treatment is by overspray directly onto the adjacent water surface or onto areas that will be covered by water on the next tide. Herbicide may also be washed off plants by subsequent tidal inundation, or potentially by precipitation (although the

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.

Spartina treatment occurs during the dry season for San Francisco Bay where there is little measurable rainfall).

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

Applications from backpack sprayers, conventional spray truck, or airboat entails workers walking along the high marsh ecotone or through the marsh, applying herbicide directly to target plants with limited overspray to surrounding plants or water surfaces. Spot application from amphibious tracked vehicles or boats entails vehicles moving through the marsh or adjacent waterway applying herbicide with hand-held equipment to target vegetation with limited overspray. Aerial application is conducted by helicopter (the imazapyr label does not allow for fixed-wing aircraft to be used) from a boom sprayer (a horizontal pipe with spray nozzles along its length, mounted to the bottom of the helicopter). Broadcast aerial application involving a boom sprayer results in a wider dispersion of herbicide, with greater potential for overspray onto non-target areas or the water surface. However, for aerial treatment on smaller patches of invasive *Spartina*, the boom may be shortened up and the apparatus turned on only when over the target vegetation. 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, and where the work is more than a quarter mile from sensitive receptors.

Environmental Fate of Herbicides

Herbicide residues 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 (summer to early autumn in the San Francisco Bay region), and herbicide applications would be postponed if significant rainfall was predicted, but tidal inundation is inevitable 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 entering the water column as a residue.

Food-web scale 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.

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 handheld 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® and Polaris™ 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 handheld 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

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 is 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 bioaccumulation factor (BAF) of 3 was calculated for imazapyr, which suggests a low potential for bioconcentration in aquatic organisms (Leson & Associates 2005). U.S. EPA considers compounds with a BAF less than 100 to have low bioaccumulation potential as shown in the table above.

Imazapyr is relatively mobile in soils because it only weakly adsorbs to soils and sediments. 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).

Conditions in sediments differ substantially from those in soils, both in terms of the regular exchange of waters within the sediment pore water, 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.

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 penetrate the leaf cuticle 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 over the past several years has found a standard reduction in imazapyr in the adjacent surface water of 92-99% just one-week post-treatment over the amount present in the adjacent surface water immediately after the application.

In estuarine systems, dilution of imazapyr by 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, Patten observed that native vegetation rapidly 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. The ISP has routinely observed this phenomenon of rapid native plant colonization of treated areas at many sites around San Francisco Bay since 2005, usually involving passive revegetation by either annual pickleweed (*Salicornia europaea*), perennial pickleweed (*Sarcocornia pacifica*), or *Jaumea carnosa*.

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 irreversibly 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 bioaccumulate.

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 freshwater (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 in 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 (<3 hrs 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 FIFRA label instructions) of herbicides registered for use in the estuarine environment are not expected to degrade water quality, except to a limited temporal and spatial extent.

In summary, the use of imazapyr or glyphosate combined with a surfactant to treat infestations of non-native cordgrass results in less than significant impacts on water quality due to the rapid degradation rate and controlled application of herbicides to the target plants. Since application of herbicide 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 and identify likely receptors and exposure pathways. The conceptual model (**Figure 2**) includes identification of primary and secondary herbicide sources, illustrates the links between sources, release and transport mechanisms, affected media, exposure routes, and potentially exposed 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 toxic nature of 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. 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 in-

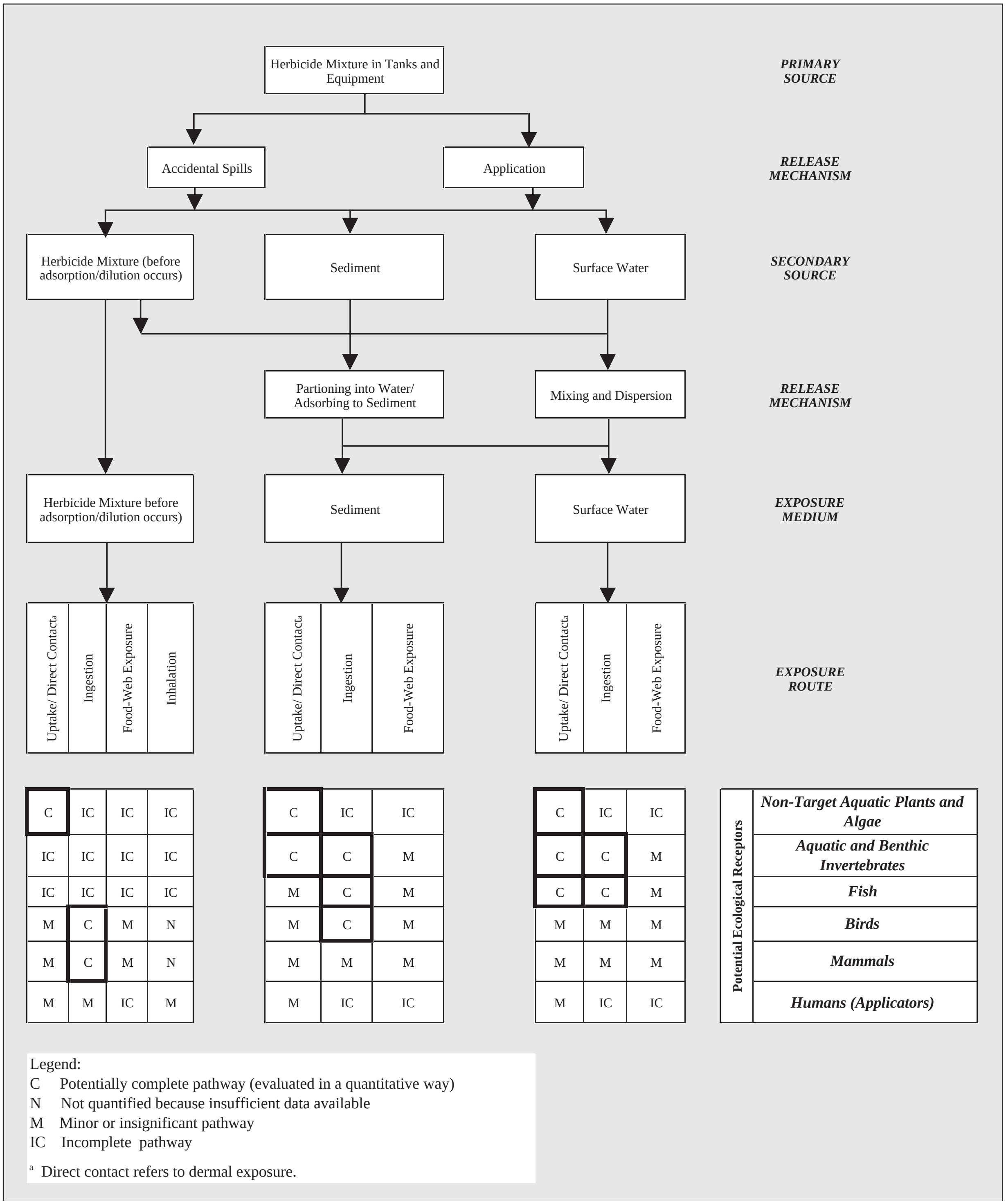

Figure 2. Conceptual Model of Possible Exposure of Biological Organisms to Herbicide Mixture Used by the *Spartina* Control Program

volved 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 application site, and frequent movement, ranging habits, and furry or feathery outer skin of most wildlife species.

Because ISP applications of herbicides normally occur only once or (at most) twice a year at a given infestation site, and compounds in the herbicide mixture are not expected to persist in significant concentrations, chronic exposure is not likely. In addition, since the aquatic formulation of imazapyr was 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 residues in the 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 submersed aquatic vegetation.

Imazapyr. The species most sensitive to technical grade imazapyr and an herbicide/surfactant mixture appear to be freshwater 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 the perennial *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 reported from the sediment underlying these eelgrass beds (Patten 2003). ISP partners have not experienced a situation where eelgrass beds are growing near the target *Spartina* in the San Francisco Estuary, so no collateral damage is expected to this species.

Glyphosate. In laboratory growth inhibition studies with submersed 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 to particulates 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 EC_{50} 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 produced a 48-hour EC_{50} concentration of 373 mg imazapyr a.e./L (Cyanamid 1997 in Entrix 2003.). Another study with Arsenal® (similar to Habitat® but only labeled for terrestrial use) 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 4^{th} 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 exposure to chemicals (U.S. EPA 2005). A recent study suggests that Habitat® has relatively low toxicity to juvenile rainbow trout. The LC_{50} determined for Arsenal® (a terrestrial formulation similar 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 beause they were used in terrestrial systems for forestry, 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 a 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, these results suggest that imazapyr is practically non-toxic to birds through the oral pathway. No data exist for the potential toxicity of imazapyr to shorebirds (Fletcher 1983a,b,c,d in SERA 2004). However, research in Washington State (Patten & Stenvall 2002) indicates that shorebirds do not forage within stands of non-native *Spartina*, which reduces or eliminates their exposure via the ingestion pathway. 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 NOEC of 1,000 ppm in the diet (Heydens 1991 in WS FEIS 1993). Little data is 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 by dermal exposure (Entrix 2003, p. 42-44). Chronic and subchronic toxicity studies with imazapyr utilizing dogs, mice, and rats as test subjects 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 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 and concentration of solution applied, and the number of subsequent 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, and the interference of 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.

Receiving Water Monitoring Triggers

In the proposed revisions to the Statewide General NPDES Permit for Aquatic Weed Control released June 27, 2012, the State Water Resources Control Board describes new Receiving Water Monitoring Triggers. In the absence of Receiving Water Limitations or other adopted criteria, objectives or standards for imazapyr, the State Water Board used data from the U.S. EPA Office of Pesticides Ecotoxicity Database to develop Receiving Water Monitoring Triggers to protect all beneficial uses of the receiving water. Toxicity studies were reviewed and a monitoring trigger was set at one-tenth of the lowest LC_{50} (lethal concentration that killed 50% of a test species in laboratory toxicity tests) for the most sensitive freshwater aquatic species. The most sensitive species in this review of the literature by the Water Board was rainbow trout, with a 96 hour LC_{50} of 112 mg/L; consequently, the monitoring trigger was set at 11.2 mg/L. However, according to the language in the proposed permit, exceeding the monitoring trigger does not constitute a violation of this General Permit but rather requires the Discharger to perform certain specified actions including additional investigations and BMP's. Based on the past seven years of water quality monitoring, the coalition of ISP partners does not anticipate that applications of imazapyr to eradicate invasive *Spartina* will ever reach this new trigger. The highest concentration found in a treatment event sample in 2011 was 0.38 mg/L, almost two full orders of magnitude below this new standard.

7. DESCRIPTION OF ALTERNATE, NON-CHEMICAL CONTROL METHODS

The *Spartina* Control Program implements a number of non-chemical control methods in situations where other forms of treatment could be more effective, environmental impacts could be reduced, sites are appropriate for volunteer efforts and educational opportunities, or where local ordinances dictate. These methods are especially appropriate for small, newly establishing infestations, and are most appropriate for *Spartina densiflora* since it is a discretely-rooted bunchgrass. 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 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, manual excavation and covering/tarping) continue to be incorporated into the most recent Site-Specific Plans. The remainder of the methods that were evaluated were found to have significant limitations, and are not part of ISP's current plans. However, some of these methods may be used in conjunction with the 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 seedlings out of soft marsh sediments or using hand tools such as spades, mattocks, or similar tools to excavate larger plants. Manual removal methods are effective primarily at removing aboveground plant parts, or the discrete root system of *Spartina densiflora*, but are much less effective at removing rhizomes (the horizontal underground stem that sends out roots and shoots from buds) from species like hybrid *Spartina alterniflora* 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 to the severity of the disturbance. Frequent re-digging and maintenance is needed to attempt to exhaust rhizome reserves of energy and nutrients, and reduce the population of buds capable of resprouting.

For hybrid *Spartina alterniflora*, the main target plant of ISP around the Estuary, manual removal is only effective on isolated seedlings, or very young discrete clones (asexually reproducing colonies of cordgrass). 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, so heavy bags of the removed vegetation and substrate must be hauled manually from the site for proper disposal.

As the invasive *Spartina* populations are reduced around San Francisco Bay, the ISP has increased its use of manual removal methods as part of an Integrated Pest Management (IPM) strategy and a way to reduce the need for herbicide where appropriate. Manual removal is particularly useful on *Spartina densiflora*, the second most common invasive cordgrass species in the Estuary which is a discretely-rooted bunchgrass as opposed to the deeply-rooted rhizomatous clones of the main problem species, hybrid *Spartina alterniflora*. The infestations of *S. densiflora* occur mainly in Marin County with the exception of a few outlier populations in Contra Costa and San Mateo Counties. Many tons of *S. densiflora* have been removed manually over the years, and as of 2011 virtually all of the *S. densiflora* infestations that remain around the Bay are managed with purely manual methods to complete the eradication.

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.

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 could 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 could be performed without entry of equipment to aquatic or wetland environments.

Mechanical excavation working to the full depth of the rhizome system (up to three feet) 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 this maintenance work, removal of invasive cordgrass involves a randomized, mosaic pattern, 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 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.

Aside from the feasibility of these scenarios listed above, excavation or maceration with heavy equipment has been evaluated by ISP partners as simply too damaging to the sensitive estuarine ecosystem, resulting in long-term alterations and scars. If the marsh plain is excavated down to the full depth of the rhizome system of hybrid *S. alterniflora*, the elevation of that area has been reduced for many years until sufficient sediment can accrete and native plants can establish at an appropriate level of tidal inundation. The disturbance from excavation is also likely to increase erosion by removing the anchoring effects of the vegetation, and can have short-term water quality impacts from the suspended sediment released. When large-scale invasive *Spartina* control is evaluated for the most appropriate method, the use of aquatic herbicide presents a far lower impact than excavation or maceration.

Covering/tarping

This technique is intended to exhaust the reserves of energy and nutrients in cordgrass roots and rhizomes and increase the environmental and disease stress on the plants. Covering typically involves securing opaque geotextile fabric completely over a patch of cordgrass. This excludes light essential to photosynthesis and "bakes" the covered grass in a tent of high temperature and humidity.

This technique may be used for discrete 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 method difficult or impossible to implement in some situations. Care must be taken to cover the entire clone to a distance sufficient to cover all rhizomes, as well as a buffer around the entire clone to account for vegetative expansion. 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 on soft mudflats is very difficult, and may make this method infeasible for most situations at this elevation.

Other Non-chemical Methods Evaluated

Mowing, burning, pruning, and flaming

Cordgrasses (as well as most other grasses) are well adapted to disturbances that "crop" or otherwise remove aboveground biomass because they have evolved with a variety of herbivores. A single event that removes living aboveground cordgrass biomass generally stimulates cordgrass growth, and as soon as a cordgrass stand refoliates, it begins to "re-charge" its roots and rhizomes with new food reserves. If vegetation is removed with frequency, roots and rhizomes may be prevented from regenerating reserves of energy and nutrition and eventually cordgrass may be killed as its organs of regeneration and storage become exhausted, however this could take many applications throughout the growing season to be successful. If the cordgrass is mown close to the mud surface, it also severs the connections in the leaves (the aerenchyma) that transport oxygen down to roots growing in anoxic, waterlogged sediment, and this could 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 hybrid *S. alterniflora*, mowing has never been found to be an effective eradication tool, so there is no way to know how many times the technique would have to be implemented to reach the goal. However, mowing has been effectively implemented by ISP as part of their IPM strategy for the eradication of *S. densiflora*. This species of cordgrass does not lose all of its aboveground biomass each year during senescence, so stands that were previously treated with herbicide but did not die fully are restricted from producing enough new green growth to conduct another application the following year. Mowing was used to stress the plants and to remove the standing biomass so the status of each plant could be evaluated and an appropriate follow-up treatment implemented where necessary. This method was implemented from 2008-2010 and was so successful that it could be discontinued entirely in 2011 in favor of manual removal.

Controlled burning could 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 (normally 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, and there is likely to be significant collateral damage to other marsh vegetation and potentially to endangered species that call these systems home.

Selective pruning (partial mowing with "weed-whackers" or flaming with hand torches) may be used to remove flowerheads and seedheads of discrete clones of hybrid *S. alterniflora* 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 an amphibious tracked vehicle 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 never been used in the San Francisco Estuary.

Flooding and draining

Flooding and draining techniques entail constructing temporary dikes or other structures (or in some cases simply closing existing flood control structures) to impound standing water or remove water to kill emergent vegetation. Cordgrasses are intolerant of permanent flooding as well as 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 soil chemistry and structure, and the longer salt marsh soils are diked and drained the more difficult these adverse soil changes would be 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 young 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 this form of 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. Mudflat 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. 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 the already high cost of these methods making them infeasible for ISP.

8. HERBICIDE APPLICATION AREAS FOR 2012

Twenty-four sites containing 162 sub-areas and less than 50 acres of non-native *Spartina* are slated for treatment during the 2012 *Spartina* Treatment Season (Figure 3). Approximately 145 of the sub-areas will potentially be treated with herbicide for at least a portion of their control work, while 13 sub-areas will utilize only manual methods (on *Spartina densiflora* near eradication) and six sub-areas will receive no treatment pursuant to the requirements of USFWS in ISP's Biological Opinion for 2012. Most of the treatment sites are receiving follow-up applications and are approaching eradication, hence the significant reduction in baywide treatment area from over 800 net acres in 2006. In the cases where it will be utilized, aquatic herbicide was determined to be the most efficacious 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 efficacy of non-chemical control methods for specific infestations, partner involvement, stakeholder input, 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 1 – 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 mi^2 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.

The combined infestation of the six sub-areas of the Alameda Flood Control Channel comprised one of the largest hybrid S*partina alterniflora* infestations in San Francisco

Figure 3. Location of 2012 *Spartina* Treatment Sites within the San Francisco Estuary. Each treatment site is comprised of 1-23 sub-areas, which are identified by letters (a through z) in project plans and documents

Bay marsh and tidal mudflats prior to treatment. The treatments from 2005 -2011 have reduced the infestation by at least 99% and only 1-2 acres remain scattered across the sub-areas in 2012. The treatment method at this site is aquatic herbicide, which will be applied by backpack sprayers since the infestation has now been reduced below the level of broadcast aerial or even amphibious tracked vehicles. 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 2 – Bair & Greco Island Complex, San Mateo County

The Bair & Greco Island complex 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. The southern border of the complex is the Union Pacific railroad line adjacent to the SF2 South Bay Salt Ponds restoration site 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 bayfront 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. Since much of this site complex is comprised of island sub-areas with significant mobilization challenges, it has been difficult to get complete treatment in any given year, but five years of effective herbicide treatments in this complex leave less than 20 net acres to treat/retreat in 2012.

USFWS is requiring through the Biological Opinion that portions of one sub-area (2c) just receive seed suppression in 2012 to minimize potential impacts to clapper rails from the loss of hybrid *Spartina* cover. Seed suppression involves the application of a dilute solution of aquatic herbicide that will arrest the development of the plant to stop seed dispersal. Since full mortality of the treated plants will not be achieved, most of the aboveground biomass will be preserved for another year to help clapper rails transition. The treatment method at this site is aquatic herbicide, which will be applied by airboat, conventional spray truck, backpack sprayer, and in the case of seed suppression, helicopter. Partners on this site include the U.S. Fish and Wildlife Service, Don Edwards National Wildlife Refuge, the San Mateo County Mosquito & Vector Control District, and 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 3 – 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 one acre in 2005, divided between two sub-areas. This has been reduced to less than about 450 ft^2 that will be treated in 2012. 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 public works project, but only the invasive *Spartina* in the center of the creek was actually removed; the remainder was treated for the first time in 2006. The primary treatment method at this site is manual removal and offsite disposal of the remaining seedlings of *S. den-*

siflora, and a small application of aquatic herbicide on the hybrid *S. alterniflora* that cannot be readily removed by digging. The imazapyr will be applied by backpack sprayer. Partners on this site include the City of Tiburon Public Works, Tiburon Audubon Society, and California Wildlife Foundation.

Site 4 – 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 both residential and commercial facilities. This ISP site complex is comprised of 12 distinct sub-areas that occur on both public and private lands, each of which requires different treatment and public outreach approaches.

The infestation at the Corte Madera Creek complex was still in a relatively early stage of establishment at the inception of ISP, 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 Estuary, as well as the first documented case of *Spartina densiflora* hybridizing with the native *Spartina foliosa* (which became a relatively common occurrence in 2008-2009 where both species existed in close proximity). Most of the sub-areas have tiny *S. densiflora* infestations remaining that allow for purely manual control to be used to complete the eradication. Several sub-areas also have hybrid *Spartina alterniflora*, bringing the overall site total to four of the five invasive cordgrass species currently found in the Bay.

The Conservation Corps North Bay (formerly Marin Conservation Corps), Friends of Corte Madera Creek and ISP conducted a great deal of manual removal throughout the winters of 2005-2011, and this method had proven highly effective to help complete the eradication work begun with imazapyr, leaving less than 0.2 acre of invasive *Spartina* in this watershed. All of the sites that shifted from chemical to manual control will be revisited this season to manually pull/dig the few plants that have resprouted or emerged from the seedbank, while any healthy *Spartina densiflora* plants will be treated with imazapyr at the larger infestations at Creekside Park and the left bank of the Corte Madera Creek mouth. 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 5 – Coyote Creek & Mowry Slough Area, Alameda & Santa Clara Counties

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) and LaRiviere Marsh (sub-area 5d). Within this site complex the sub-areas include restored tidal marshes as well as highly complex and diverse historic marsh habitats that include well-developed channels, high marsh, mudflats, pans, and thin strip marshes.

The pioneering infestation of hybrid *Spartina alterniflora* in the Coyote Creek and Mowry Slough complex was limited in its distribution at the inception of ISP, although some cryptic hybrid morphologies were still evolving within stands of native *S. foliosa* that weren't detected until 2008. 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. The results from 2007 treatment were less efficacious and several of these areas need to be treated by broadcast aerial application in 2008 after they had expanded. In 2009, a more aggressive, ground-based treatment strategy was initiated throughout the Refuge in response to increasing discoveries of cryptic hybrids in this extremely valuable habitat. Imazapyr was applied by airboat and backpack sprayer, and these methods will be utilized again in 2012 on the remaining 2 net acres widely dispersed throughout the habitat types described above. The partners on this site are the U.S. Fish and Wildlife Service, Don Edwards National Wildlife Refuge 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 6 – Emeryville Crescent, Alameda County

The Emeryville Crescent marsh is a 103.5-acre, fringing mixed pickleweed (*Sarcocornia pacifica*) marsh shoreline between Powell Street in Emeryville and the eastern landfall of the San Francisco 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 Bay Bridge adjacent to the south. Local anglers 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 were in the early stages of establishment on the site in 2005, at less than 2.6 acres or 2.5% of the combined marsh acreage. The infestation was 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 that were establishing on the interior portions of the marsh within sub-area 6b. Several new hybrid areas appeared since 2008 that were developing within the extensive *S. foliosa* band and were hard to detect until they reached critical mass. Treatment in 2012 will be required on less than 0.1 acre after several years of thorough applications with high efficacy. The primary treatment method at this site is aquatic herbicide, which will be applied by backpack sprayer. Partners on this site include the California Department of Parks and Recreation and the East Bay Regional Parks District.

Site 7 – 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 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 hybrid *Spartina alterniflora* across both sub-areas prior to successful helicopter treatment in 2005, totaling approximately 100 acres (31% of the marsh). This was one of the largest infestations of hybrid *S. alterniflora* in the eastern Central Bay, and was adjacent to several other large infestations including sites along the San Leandro/ Hayward shoreline. Successful helicopter treatments also occurred in 2006 & 2007, and scattered clusters of *Spartina* throughout the site were treated from 2008-2011 by Hydrotraxx and airboat, leaving less than one acre in 2012. The primary treatment method for 2012 at this site is aquatic herbicide, which will be applied to the remaining stands and scattered plants by airboat and backpacks. The partner on this site is the East Bay Regional Parks District.

Site 8 – 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 all marshland from San Francisquito Creek south to Charleston Slough. The site is part of a large expanse of intact native *Spartina foliosa* and pickleweed (*Sarcocornia pacifica*)/gumplant (*Grindelia stricta*) 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 hybrid *S. alterniflora* on this site covered approximately one acre in 2005, scattered along the bayfront, mostly south of the Baylands Nature Interpretive Center, but discovery of numerous cryptic hybrid forms over the years indicates the original infestation was significantly larger but had not yet developed the critical mass to be detected amongst so much *S. foliosa*. Treatment from 2005-2011 has eliminated most of the original infestation areas, and kept new discoveries from expanding into significant problems. 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 treatment method at this site is aquatic herbicide, which will be applied to about 0.3 acre of hybrid *Spartina* by backpack sprayer and truck & hose, with one area only accessible by boat. Partners on this site include the City of Palo Alto and Palo Alto High School.

Site 9 – Tiscornia Marsh (formerly Pickleweed Park), Marin County

Tiscornia Marsh is an 10-acre Marin Audubon site (formerly a 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, with the community center at Pickleweed Park on the western border. The marsh is comprised of a thin band of high marsh pickleweed/gumplant habitat, which grades abruptly from a 4-5 foot 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.

At the inception of ISP's efforts in this area in 2004, there was a well-established population of *Spartina densiflora* within the fringing marshlands of the park. These plants were at their greatest density in the marsh near the outlet of San Rafael Creek and formed a dense stand on the Bay edge surrounding the escarpment near an electrical tower. Scattered plants extended 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 acre. In spring 2005, a pioneering infestation of hybrid *S. alterniflora* was also discovered just south of the PG&E walkway. Treatment from 2005-2011 has been highly effective and just a handful of plants will need to be treated in 2012. The primary treatment method at this site is manual removal of all *S. densiflora*, with very limited aquatic herbicide application by backpack sprayer to one or two small patches of hybrid *S. alterniflora* regrowth. Partners on this site include Marin Audubon, City of San Rafael, and California Wildlife Foundation.

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 on the western edge 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 is the historical Whittell Marsh (sub-area 10a), characterized by an extensive pickleweed marshplain and *Grindelia*-lined channels. Southern Marsh (sub-area 10b) on the other end of the park is a narrow band of tidal marsh grading quickly over a 10-20 meter span from high marsh pickleweed to sandy mudflat. Sub-area 10c was added in 2008 with EBRPD's acquisition of Giant Marsh, which is comprised of a thin pickleweed marshplain criss-crossed by tidal ditches created during a prior era.

The non-native *Spartina* infestations at Point Pinole were in the early stages of establishment at the onset of treatment. The plants are scattered throughout the sub-areas, but their overall acreage is very small. Giant Marsh was first treated in 2008. The primary treatment method for the 0.02 acre of *Spartina* remaining at this site is aquatic herbicide, which will be applied by backpack sprayer. All *S. densiflora* (primarily in Whittell Marsh that does not have any hybrid *S. alterniflora*) will be removed manually and disposed of off-site. The partner on this site is the East Bay Regional Parks District.

Site 11 – Southampton Marsh, Solano 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 to the west stands residential development within the City 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 annual plant species, can be found in some areas of the marshplain and along several channel banks. Access to the marsh is restricted to park personnel and researchers to protect these rare plant populations and other ecological aspects of the site from potential damage.

Southampton Marsh contains the only known population of *Spartina patens* in the San Francisco Estuary. Several large clones were scattered throughout the southern and western portions of the marsh prior to the initiation of treatment, with multiple smaller clones peppered throughout the area including several adjacent to the main channel. There was less than an acre of *S. patens* at this site in 2005, which has been 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.* In 2012, State Parks and ISP developed a new strategy to make more progress on this lingering infestation. Seedlings and small *S. patens* on the marsh plain will be dug while the final remaining stands along the channel will be tarped. There are also several cryptic hybrid *S. alterniflora* forms that were first identified in 2008, and these have been added to the necessary control work. The primary treatment method at this site is digging and tarping for *S. patens* and aquatic herbicide for the trace amount of hybrid *S. alterniflora*, 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 Mission Creek to 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 the San Francisco 49er's 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 nine sub-areas of the Southeast San Francisco complex contained approximately 8.2 acres of hybrid *Spartina alterniflora* in 2005. This represents 14.5% of the area of these fragmented remnant marshlands. The individual patches of non-native *Spartina* within this area represented localized 'stepping stones' in the available marsh habitat of the area to the open waters of the relatively lightly-infested North Bay. Treatment occurred at most of these sites from 2006 to 2011, reducing the area needing treatment in 2012 to less than 0.1 acre. The treatment methods at this site include a combination of manual digging and application of aquatic herbicide by conventional spray truck or backpack. 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, California Wildlife Foundation, 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 historical 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 almost 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 & 13i-l), or by Alameda County Flood Control District for flood control purposes (Sub-Areas 13a, 13b, 13c, 13g, 13h). 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 hybrid *Spartina alterniflora* representing 14.5% of the area. Applications from 2005 -2011 were very effective, reducing the area to be treated in 2012 to less than 0.5 acre, mostly scattered in channels and other low elevation areas. The infestations are approaching eradication throughout the site in a wide variety of marsh habitats including high marsh pickleweed (*Sarcocornia pacifica*)/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 became infested with large, coalescing clones of invasive *Spartina*. On the eastern portion of the site, these clones had coalesced into meadows. The Cargill Mitigation Marsh sub-area contained approximately 19 acres of *S. alterniflora* hybrids, representing 38.8% of this restoration site in 2005. Treatment over the past six years has reduced the infestation substantially, with less than 0.1 acre scattered over the site left to treat in 2012. Sub-areas 13i-13l have been added in recent years as they have been breached and once again open to tidal exchange, and these sub-areas are similar to Cargill Mitigation Marsh in that the absence of biotic resistance makes them susceptible to *Spartina* invasion and rapid widespread establishment in the absence of treatment.

The treatment method at this site is aquatic herbicide, which will be applied by backpack and truck (successful treatment has eliminated the need for helicopter application as of 2009 as well as amphibious tracked vehicle after 2010). 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 far southern tip of the San Francisco Bay in Santa Clara County, 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, intact remnant salt marsh, 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, Permanente Creek, outer Charleston 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 infestation was approximately 8 acres in 2005, but it had expanded rapidly until 2008 despite the effectiveness of imazapyr, largely due to previously-undetected cryptic hybrids and post-September 1 treatment. The majority of the infestation occurs in the area of Knapp Tract, on Alviso and Guadalupe Sloughs, and along the bayfront adjacent to the DENWR newly acquired 'salt ponds' A1 and A2W. Both Ponds A1 and A2W marshes are composed of large expanses of intact native *Spartina foliosa* (California cordgrass) and pickleweed (*Sarcocornia pacifica*), 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 portions of the site are patchy and scattered throughout the far South Bay extending from Charleston Slough in the northwest to the Coyote Creek tidelands in the northeast.

Until 2008 the marshes of Faber Laumeister were thought to be free from hybrid *Spartina*, but surveys and genetic testing showed that this area required treatment for the first time in 2009. Both Faber Laumeister and Stevens Creek Tidal Marsh (in Shoreline Regional Park) have been effectively treated and their infestations are approaching eradication. The primary treatment method at this site is aquatic herbicide, which will be applied by conventional spray truck and backpack sprayer to approximately 0.75 net acre. Partners on this site include the Santa Clara Valley Water District, City of Mountain View, U.S. Fish and Wildlife Service, Don Edwards National Wildlife Refuge, and the California Wildlife Foundation.

Site 16 – Cooley Landing, San Mateo County

Cooley Landing is a 165-acre salt marsh restoration site located on the western shoreline of the Estuary in East Palo Alto, 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. Revegetation of the former salt pond was expected to occur through natural colonization as opposed to active planting. Performance criteria for the restoration of Cooley Landing required 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 some hybrid *S. alterniflora* was known to occur both 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 acres of the restoration site or 13 % of this large area by 2005. Treatment from 2006-2011 has reduced the infestation by 85%, but a significant amount of hybrid *Spartina* will be need to be treated in 2012 and this invader is still present to varying degrees throughout the site. USFWS Sacramento required in ISP's Biological Opinion that a majority of this site not be treated in 2011, so the remaining infestation in that area was allowed to rebound and expand, leaving approximately 2 net acres of hybrid for 2012 treatment. The treatment method at this site is aquatic herbicide, which will be applied by airboat, backpack and truck. Partners on this site include S.S. Papadopoulos Associates, Midpeninsula Regional Open Space District, and the California Wildlife Foundation.

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

This ISP site complex 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 within such a highly developed land matrix. 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 and were very well established at the initiation of treatment. In 2005, the shoreline of this site contained 88.5 acres of non-native *Spartina* targeted for control by ISP partners. Arrowhead Marsh, MLK New Marsh and Fan Marsh supported the largest infestations of *Spartina* in the Alameda and San Leandro Bay Complex and none of these were permitted for treatment in 2011 pursuant to ISP's Biological Opinion (BO) from USFWS; of these sub-areas, only the western half of Arrowhead Marsh will be permitted for treatment in the 2012 BO and the infestation at Damon Marsh on the eastern shoreline will also be allowed to rebound and expand.

Treatment from 2005 -2010 has reduced the overall infestation significantly throughout the complex, but some sites have only received seed suppression treatments and consequently are still heavily infested. The treatment method for 2012 at this site complex is aquatic herbicide, which will be applied by conventional spray truck, backpack sprayer, and airboat to approximately one net acre of hybrid *Spartina*. 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 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 18 – Colma Creek / San Bruno Marsh Complex, San Mateo County

This ISP site complex includes all of the marshlands north of the San Francisco International Airport, up to the northern tip of the outlet of Colma Creek. Within this area there are broad mudflats and fringe marsh along the shoreline of the industrial fill of South San Francisco, pickleweed and gumplant-lined flood control channels, and upland marsh ecotones. 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. There were an estimated 100.3 acres of marshland within this site in 2005, a substantial portion of which was created and dominated by hybrid *Spartina alterniflora*.

The *Spartina* infestations within this site are distributed throughout the habitat types described above. In sum, the marshes of this site contained about 60 acres of non-native *Spartina* at the inception of control efforts, representing 60% of the possible habitat. The infestation of this ecosystem engineer had rapidly expanded onto the open mudflats on the western portion of this site, accreting sediment and raising the elevation to a more suitable level within the tidal regime, as well as constricting the flood control channels on the northern and southern portions.

Non-native *Spartina* had 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 was phased over several years, with only the upper channels receiving applications in 2006. The entire site was treated in 2007, with approximately 60% just “chemically mowed” with a low, sub-lethal concentration of imazapyr to stop seed production while maintaining the above-ground biomass for rail refugia. In 2008, all remaining hybrid *Spartina* was treated with the full concentration of imazapyr. This strategy was remarkably successful and less than one net acre remains scattered over the complex as of 2012, with the western portion of San Bruno Marsh now largely devoid of *Spartina* after just five treatments. The treatment method for 2012 at this site complex is aquatic herbicide, which will be applied by airboat, backpack sprayer, and possibly conventional spray truck along the upland ecotone. Partners on this site include the San Mateo County Mosquito & Vector Control District, San Mateo County Flood Control District, City of South San Francisco, and the San Mateo County Transit District (SamTrans). 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

This ISP site complex 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. 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, but all sites are fragmented from the historical marsh matrix. Only a few of these sub-areas support a diverse marsh, and hybrid *Spartina* came 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 beaches, within large established marsh, in wide lagoons, on shallow mudflats, and in small coves and sheltered crannies all along the Bay shoreline. In all sub-areas, hybrid *Spartina* was rapidly expanding into the existing available habitat. Out of an estimated 350 acres of marsh habitat covered by this complex, there were 85 net acres (24%) of hybrid *Spartina* requiring control in 2005. Years of successful treatment by SMCMVCD has reduced this site complex to approximately 3 net acres to be treated in 2012. The primary treatment method at this site is aquatic herbicide, which will be applied by airboat and backpack sprayer.

Site 19 included two sites (Sanchez and Burlingame Lagoons) that contained small infestations of *Spartina densiflora* that had been transplanted anonymously at some point in the past. Successful imazapyr treatment in 2008 had reduced this *S. densiflora* infestation to the point of purely manual removal by 2009, and this method will be used again in 2012 to continue the eradication if any plants of this species remain. Partners on this site include the San Mateo County Mosquito & Vector Control 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, City of South San Francisco, U.S. Coast Guard Reservation, 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

This ISP site complex includes the marshlands of the San Leandro and Hayward shoreline, Alameda County, extending south from the Metrolinks Golf Course and Oakland International Airport in the north to the San Mateo-Hayward Bridge in the south. The marshland areas in this site complex range from large, complex restored marsh systems to channel-bank fringe marsh. 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 and within EBRPD lands.

The infestations of non-native *Spartina* that constitute the San Leandro and Hayward Shoreline Complex are located 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 mudflats, and in small coves and sheltered marsh areas along the Bay edge. Of 580 acres of marsh habitat within this complex, there were an estimated 204 net acres of non-native *Spartina* requiring control in 2005, representing 35% of the area. Treatment from 2005 -2011 has reduced this infestation by over 90%, leaving approximately 8 acres by 2012. Several large sites were not treated in 2011 pursuant to the ISP's Biological Opinion from USFWS and this continues to be the permit status for these sites in 2012. This includes much of the Robert's Landing complex (Sites 20d, 20f, & 20g) as well as two of the three sections of Cogswell Marsh (20n & 20o). The treatment method at this site complex is aquatic herbicide, which will be applied by airboat, conventional spray truck, and backpack sprayer. Partners on this site include the Alameda County Flood Control District, California Wildlife Foundation, 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 179-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 after a levee was breached in a storm. The shoreline marshes of this site stretch for approximately 2.5 miles south of the Alameda Flood Control 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 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 invasive *Spartina*, with a total of 98 acres of hybrid *Spartina alterniflora* in 2006 representing 54% of the marshlands at Ideal Marsh. These plants occupied all habitat types present in these marshes, including open mudflats, sand/shell beaches, eroding marsh edge, pickleweed plain, levee edge and other areas. Helicopter treatment from 2005-2008 reduced the infestation by 85% or more. The area was treated by backpack for the first time in 2009 with a supporting helicopter application only along the bayfront. The site now contains just small patches and individual hybrid *S. alterniflora* plants scattered across the marsh plain and in a few of the channels, with a moderate infestation still present along the bayfront (possibly related to tidal inundation and dry time). The treatment method at this site is aquatic herbicide, which will be applied to approximately one net acre by airboat, backpack sprayer and conventional spray truck in 2012. The partner on this site is the U.S. Fish and Wildlife Service, Don Edwards National Wildlife Refuge and California Wildlife Foundation.

Site 22 – Two Points Complex, Alameda and Contra Costa Counties

The Two Points Complex is located on the east side of north San Francisco Bay and southeast San Pablo Bay, along the shoreline of the Cities of Richmond, Pinole, Hercules and Rodeo. It 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 many of the marshes in the complex. The tidal systems of this complex include several large, intact historical marshes, many fringing marshes with mixed pickleweed/*Spartina* vegetation assemblages, mudflats and flood control channels.

The infestations at the Two Points Complex were still in the early stages of establishment at the inception of ISP control efforts, with approximately 5 acres scattered over the 598 acres of the six sub-areas, or less than 1% of the total marsh area. The establishing clonal patches within this area were located mostly along the bayfront amongst native *Spartina* stands or along the banks of small channels within the marshes, and several areas had begun to coalesce into meadows. The channels and marsh plain of San Pablo Marsh were being rapidly invaded until treatment began in 2005 on the western portion and 2007 for the eastern. The easternmost portion of San Pablo Marsh was treated for the first time in 2008 because the plants senesced early ahead of treatment in both 2006 & 2007. The treatment method at this site for 2012 is aquatic herbicide, applied by airboat, backpack sprayers and truck to approximately 2 net acres of hybrid *Spartina*. Partners on this site include the State of California Lands Commission, California Wildlife Foundation, Republic Services, Chevron/Texaco, Richmond Rod and Gun Club, 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

This ISP site complex includes selected marshlands within eastern Marin County extending south from Novato to Sausalito. Many of the sub areas are small marshes or mudflat areas bordered by residential or commercial development, while 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. Non-native *Spartina* was in the relatively early stages of expansion into the existing habitat throughout the site complex in 2005 at the inception of treatment; of an estimated 130 acres of marsh habitat within the complex there were 2.6 net acres of non-native *Spartina* representing 2% of the marsh area.

Most of these infestations are now down to only a few hundred square feet or less after effective treatments from 2005 -2011. The primary treatment method at a number of sites in this complex is manual removal of *S. densiflora* after the reductions realized over the past several control seasons using imazapyr. Other sites will still depend on aquatic herbicide treatment (because of the rhizomatous nature of hybrid *S. alterniflora*), which will be applied by backpack sprayer to less than 0.5 acre. Partners on this site include Marin Audubon, County of Marin, California Department of Fish & Game, California Wildlife Foundation, Loch Lomond Marina, Strawberry Recreation District, City of San Rafael, City of Mill Valley, City of Novato, California State Lands Commission, California State Parks, McNear Brick and Block, Paradise Cay Yacht Club, City of Sausalito, 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, restoration sites, light industrial facilities and urban development.

The pioneering infestation of hybrid *Spartina alterniflora* in the Petaluma River complex was discovered in November 2006, and was 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 of this central core. In sum, these infestations covered less than 0.1 acre scattered over this very large marshland complex, which is equal to less than 0.01% of the area. The first treatment at this site occurred in 2007 and follow up work from 2008-2011 has kept this pioneering infestation in check. Several areas of cryptic hybrids continued to develop within the extensive stands of native *S. foliosa* until they reached critical mass and could be detected during inventory monitoring. The treatment method at this site for 2012 is aquatic herbicide, which will be applied by backpack sprayer to less than 500 ft^2. 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, with additional support from California Wildlife Foundation.

Site 26 – North San Pablo Bay, Solano County

There are two main portions of this sub area: the restoration site on the east side of the Napa River called White Slough in Vallejo, and the marshes along the northern shoreline of San Pablo Bay including Mare Island, the mouth of Sonoma Creek, and Sonoma Baylands.

White Slough marsh is a roughly 135-acre restored tidal marsh that lies to the east of Highway 37 and west of Sonoma Boulevard in the City of Vallejo. The marsh is a sparsely vegetated tidal marsh in the initial stages of colonization. The majority of the area is open mudflat with tidally inundated low sections. The periphery of the marsh is composed of scattered pickleweed (*Sarcocornia pacifica*), *Spartina foliosa*, and alkali bulrush (*Bolboschoenus maritimus*). Hybrid S. alterniflora may have been eradicated from this site since none was found or treated in 2010 or 2011.

The other marsh areas included in this sub-area are the massive mudflat and shoreline area of San Pablo Bay National Wildlife Refuge on the west side of Mare Island, the mouth of Sonoma Creek, and the restored marsh of Sonoma Baylands. This large area of restored and historic tidal marsh, developed shoreline, industrial and decommissioned military facilities is only lightly infested with non-native *Spartina*, including both *S. densiflora* and hybrid *S. alterniflora*. All *S. densiflora* on Mare Island will be removed manually and disposed off-site, while any necessary hybrid treatment will be conducted by backpack sprayer to a very limited footprint under 500 ft^2.

9. WATER QUALITY MONITORING PLAN (WQMP)

Objective

Conduct water quality monitoring for ISP's coalition partners sufficient to achieve compliance with NPDES Statewide General Permit requirements.

Monitoring Site Selection

Up to 145 sites (sub-areas) of invasive *Spartina* throughout the San Francisco Bay Estuary are slated for treatment with aquatic herbicide during the 2012 control season. According to the Statewide General Permit and current NPDES requirements, ten percent (10%), or 15 of the 145 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. The WQMP has been designed to answer the two key questions articulated by the Permit:

1. Does the residual aquatic herbicide discharge cause an exceedance of receiving water limitations?
2. Does the discharge of residual aquatic herbicide, including active ingredients, inert ingredients, and degradation byproducts, in any combination cause or contribute to an exceedance of the "no toxics in toxic amount" narrative toxicity objective?

To assist with sampling site selection, 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 representative sites of each 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. For these reasons, along with the fact that ISP has reduced its Type IV sites to tiny infestations of widely-scattered individual plants, fewer sites of this type will be monitored for 2012. Site Types I and II are considered to be the sites most likely to develop detectible levels of herbicide in the water column. For 2012, the final sampling plan list includes four Type I sites, four Type II sites, four Type III sites, and three Type IV sites chosen to represent the range of herbicide delivery systems and marsh dynamics present in our work program. Imazapyr is the only herbicide that will be utilized by ISP's coalition partners for *Spartina* treatment in 2012. Table 5 provides a summary of the sites, and the sites are described in a subsequent section.

Sampling Design

The sampling events are designed to characterize the potential risk involved with imazapyr 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,

Table 5. Summary of Water Quality Monitoring Sites for the 2012 Treatment Season

Sites	*Site Number*	*Marsh Type*	*Treatment Date*	*Application*
Sonoma Creek	*26c*	*III*	*8/14/12*	*Imazapyr – Backpack*
Corte Madera Creek Mouth	*4j*	*III*	*8/20/12*	*Imazapyr – Backpack*
Creekside Park	*4g*	*I*	*8/20/12*	*Imazapyr – Backpack*
Palo Alto Baylands	*8*	*II*	*8/20/12*	*Imazapyr – Truck, Backpack*
Blackie's Creek Mouth	*3b*	*II*	*8/21/12*	*Imazapyr – Backpack*
Oyster Point Park	*19e*	*IV*	*8/21/12*	*Imazapyr – Backpack*
San Bruno Marsh	*18g*	*II*	*TBD*	*Imazapyr – Airboat*
San Pablo Marsh	*22b*	*I*	*9/4/12*	*Imazapyr – Airboat, Backpack*
Newark Slough	*5c*	*III*	*TBD*	*Imazapyr – Airboat, Backpack*
Belmont Slough	*2a*	*III*	*TBD*	*Imazapyr – Airboat, Backpack*
SFO	*19h*	*IV*	*TBD*	*Imazapyr – Airboat, Backpack*
Oakland Inner Harbor	*17f*	*IV*	*TBD*	*Imazapyr – Backpack*
Greco Island South	*2h*	*I*	*TBD*	*Imazapyr – Airboat, Backpack*
Giant Marsh	*10c*	*II*	*TBD*	*Imazapyr – Backpack*
Seal Slough	*19p*	*I*	*TBD*	*Imazapyr – Airboat, Backpack*

the point will be recorded using GPS 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 on the incoming tide. Since it is standard protocol for the ISP partners to treat *Spartina* on a low or receding tide whenever possible, application event samples will often be taken 0.5-5 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. To enhance quality assurance, the ISP will be submitting three to four duplicates to the lab over the course of the season for the corresponding 45 total base samples taken. 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 ND (not detected). It is standard for the lab to include blanks as part of their quality control, but the ISP will send additional trip blanks consisting of distilled water on a regular basis.

Field Sampling Procedures

In 2012, the Invasive *Spartina* Project will conduct its water quality monitoring program as a coalition for its partners around the Estuary as it has since 2005. Water samples will be collected using a sampling rod and pre-cleaned amber glass 1-liter bottles. To collect the sample, the bottle is attached to the sampling rod with a clamp, extended out over the water at the application site, and lowered to approximately 50% of the water depth. When the bottle is full it is pulled back out of the water and the cap is affixed to the mouth of the bottle. The sample is labeled in permanent ink with the sample ID number, date, time, and initials of the sampler.

The sample ID number is determined by the following protocol: a four-letter code unique to the site, followed by the site visit number (e.g., 01 for pre-treatment, 02 for treatment, or 03 for one-week post-treatment), followed by the time since the application (e.g., "pre" for the baseline sample, the number of hours since the application for the treatment sample, or "1w" for the one-week post-treatment).

Equipment Calibration

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). To assure accurate and reliable temperature, electrical conductivity, salinity, and dissolved oxygen measurements, the YSI Model 85 meter will be calibrated, operated, and maintained in accordance with the manual specifications found at http://www.ysi.com/media/pdfs/038503-YSI-Model-85-Operations-Manual-RevE.pdf. To assure accurate and reliable pH measurement, the pHTester 1 meter will be calibrated, operated, and maintained in accordance with the manual specifications found at http://www.4oakton.com/Manuals/pHORPIon/WPpHTestr1_2mnl.pdf.

Field Data Sheets

At each sampling location, the sample ID number, the time of the sampling, the sample depth, and the water temperature, pH, dissolved oxygen, conductivity, and salinity measurements, will be entered on a Field Data Collection Form ("FDCF", **Appendix 3**). Also recorded on the FDCF will be site information, including the site ID number, the station location (application point, upstream, downstream), station type (reference, treated), wind conditions, tidal cycle, water color, and the type of herbicide and surfactant that might be present. Any other unusual conditions or concerns will be noted, and any fish, birds, or other wildlife present will be recorded. The FDCFs will be dated and numbered consecutively for each site on that date. Data from these field forms will be entered into an electronic spreadsheet for processing, and the FDCFs will be compiled into a data log and kept permanently in the ISP office.

Sample Shipment

Following collection, water samples will be stored on ice packs and shipped for priority overnight delivery to the Pacific Agricultural Laboratory in Portland, OR. If samples are not shipped until the following day, they will be stored in a cooler on ice until they can be transferred to a refrigerator, and subsequently transferred back into a cooler for shipping.

Field Variances

The ISP usually selects and plans to monitor one to two more sites each season than is necessary for compliance with the NPDES Permit, to allow for failed sampling events or analyses. If a situation should arise that precludes being able to collect a water quality sample at a designated point suitably close to the specified times (within 24 hours prior to herbicide treatment, within several hours post-treatment, or one week post-treatment), the Water Quality Monitoring Manager (WQMM) will determine whether (1) sampling at the site type is needed to complete the sampling events required by the NPDES permit, or (2) sampling at the site type is not needed for permit compliance, and the site/event can be dropped. If the site type is needed, then the WQMM will consider whether surrogate sampling of some sort (e.g., sampling at a point reasonably nearby the initial point, or at a later or earlier time) would provide an acceptable substitute. If so, the variation will be carefully documented and justified on the Field Data Sheet. If the WQMM determines that surrogate sampling would not be suitable, then an alternate, similar site will be selected and sampled as a complete replacement for the initial site. Data from samples already collected at the initial site will be kept and reported, along with an explanation of the reason for substitution. Any significant problems with sampling events that cannot be remedied in such a way, or any other significant water quality issues that should arise, will be reported to the US EPA Region 9 Project Manager, or their designee.

Sample Analysis

The samples will be analyzed within the appropriate holding times for imazapyr (extracted within seven days, analyzed within 21 days of extraction). Results are reported as parts per billion (ppb), equivalent to µg/L. The analytical method used for imazapyr is EPA 8321B in which the extracts are analyzed using liquid chromatography with mass spectroscopy (LC/MS) detection, with a Limit of Quantitation (LOQ) of 0.1 ppb (the minimum detectable level of the analytical method). The lab runs one blank each time it conducts an analysis (minimum of one sample tested per batch, maximum of three). Results will be reported at the end of the season to the San Francisco Bay Regional Water Quality Control Board and placed on the ISP's website for public viewing.

Assessment of Field Contamination

Field Blanks. To help assess contamination from field equipment, ambient conditions, sample containers, transit, and the laboratory, one field blank will be collected and submitted for analysis on a regular basis. Field blank samples will be obtained by pouring distilled water into a sampling container at the sampling point.

Lab QC & Data Quality Indicators

Each season, the contracted analytical laboratory ("lab") is required to provide a Quality Assurance Plan (*QAP") that meets USEPA standards prior to initiating analysis. The lab plan must specify the method of analysis to be used, and describe any variations from a standard protocol. The WQMM will review the lab QAP and determine if it is adequate.

At a minimum, the following DQIs will be required for the lab:

Criteria	*Method*	*Indicator Goal*
Accuracy of measurement	Analyze matrix spikes and spike duplicates	1 matrix spike per 10 samples (10%) > 65% @ 2.0 ug/L
Agreement between measurements	Analyze lab duplicates and/or matrix spike duplicates	Relative percent difference < 25%
Completeness	Percent of usable data (completed/submitted)	95% return
Comparability of results	Standard reporting units	All data reported in micrograms per liter (ug/L) or parts per billion (ppb)
	Use of standardized analysis methods	Standard method used if possible, any modifications identified, described, and supported.
Detection Limits	Limit of Quantitation	LOQ </= 0.1 ppb

The Lab QAP submitted for 2012 is attached at **Appendix 5**.

Monitoring Site Descriptions

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

Corte Madera Creek Mouth. The main infestation area at this Type III site is an island at the mouth of Corte Madera Creek is Type III located behind the Larkspur Ferry Terminal, north across the creek channel from Greenbrae Boardwalk and the Corte Madera Ecological Reserve. This island contains the largest infestation of hybrid *S. alterniflora* in the watershed as a result of seeds being strained out of the incoming tide as propagules enter Corte Madera Creek. This site also contains a moderate infestation of *S. densiflora* that is one of the largest remaining in the Estuary. This portion of the site was not permitted for treatment in 2011, and consequently both infestations were allowed to rebound and expand. The invasive *Spartina* at the site will be treated with imazapyr in 2012; the application to flowering *S. densiflora* (before seed set) is intended to arrest plant development to eliminate any further seed bank accumulation in the substrate (or dispersal to other marshes). After clapper rail breeding season is over on September 1, Conservation Corps North Bay will manually remove the *S. densiflora* for offsite disposal.

Creekside Park. This Type I site is estimated to contain approximately 21 acres of marshland habitat adjacent to the upper portion of Corte Madera Creek just upstream of Bon Air Road. The park was restored 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 imazapyr applications conducted from 2006 to 2008 controlled the infestation and stopped most seed production, but had not succeeded in full mortality on the meadow areas of *S. densiflora* plants. Beginning in winter 2008-2009, dense areas of the infestation were mowed to bare ground to allow the remaining live plants to sprout fresh healthy growth that could either be retreated with herbicide or dug. In 2012, Creekside Park will receive an imazapyr treatment to arrest the development of *S. densiflora* seed until manual removal can be conducted after clapper rail breeding season. The application to other *Spartina* species on the site, including *S. anglica*, should be the only tool needed for eradication.

Oyster Point Park. This Type IV site is a 3.5-acre area within the 33-acre park, including the small channel that runs west to east some 350 meters from Gull Dr. along the base of a steep slope. The benches of the creek are mixed marsh habitat with some sandy beach deposits. The infestation here has been reduced to just a handful of patches and individual plants that will be treated by backpack sprayer to complete the eradication.

San Bruno Marsh. Hybrid *Spartina* established and built up this marsh over the years through the accretion of sediment on the open mudflats north of the mouth of Colma Creek. This Type II site encompasses some 14.6 total acres of marshland, mudflat, and channel. Prior to 2008 treatment, the *Spartina* here consisted of a coalesced meadow in the south and an established linear infestation along the northern shore, with expanding individual pioneer clones scattered through the northern area. This site was only treated for the first time in 2007, with some areas receiving a sub-lethal dose for seed suppression. In 2008, the full concentration treatment was extremely effective, and follow-up applications from Argo and airboat have reduced the infestation significantly. Very little hybrid *Spartina* remains in the southern meadow, and only scattered green patches throughout the northern shore. The site will be treated by airboat in 2012.

Sonoma Creek. This Type III site at the mouth of Sonoma Creek was discovered late in 2008 and eluded treatment in 2009 due to very early senescence. The banks of the creek are lined with continuous stands of native *Spartina foliosa* that stretch for miles, and these clones were not observed standing out from the crowd until they reached critical mass and an airboat survey was able to detect them. The infestation consists of two linear stands of very large plants at the mouths of two smaller channels off the eastern bank of Sonoma Creek along the northern shoreline of San Pablo Bay. These clones will be treated in 2012 by backpack sprayer.

Blackie's Creek Mouth. Blackie's Pasture is a small City of Tiburon park co-managed by the City of Tiburon and Tiburon Audubon. The park is located along the shoreline of Richardson Bay, adjacent to Tiburon Boulevard. The park is heavily used by the public for passive recreation, and 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, open mudflat, landscaped pathways and picnic areas, and rip-rap fill to the east along the Tiburon Peninsula. The mouth of Blackie's Creek, a Type II site, was heavily infested with both hybrid *S. alterniflora* and *S. densiflora*. After several years of manual and chemical control work, the infestation contains very few *S. densiflora* seedlings sprouting from the seed bank, and just scattered small patches of hybrid *S. alterniflora*. Treatment in 2012 will involve purely manual removal of seedlings of *S. densiflora* and retreatment of the remaining hybrid *S. alterniflora* by backpack sprayer.

Newark Slough. This Type III site encompasses roughly 400 acres of marsh and creek channel bank stretching from Thornton Avenue and Hickory Street in the City of Newark downstream to the edge of the abandoned railroad line, 900 meters upstream of the confluence with Plummer Creek. In its upstream reach, the wide, levee-bound slough winds sinuously through the Don Edwards San Francisco Bay National Wildlife Refuge, skirting the southwest edge of the large hillside that the Refuge headquarters sits atop, along Marshlands Road just south of the Hwy. 84 approach to the Dumbarton Bridge, and past some decommissioned salt ponds. The fringing marsh upstream of the Refuge headquarters is very wide on the north side of the channel, and contains an extremely high density of gumplant (*Grindelia stricta*) that dominates large areas of the pickleweed marsh plain.

Fringing channel bank marsh habitat borders the waters of the channel along the remainder of its length, often dropping off steeply at the channel's edge. The site will be treated mostly by airboat, possibly with some backpack sprayer work away from the channel banks.

Belmont Slough. This 448-acre, type III site includes Belmont Slough, North Point, Bird Island, and the northern shoreline along Redwood Shores. The sloughs are open tidal waters lined with strips of mixed pickleweed/*Spartina foliosa* marsh of varying widths. The shorelines and islands are comprised of thin to moderate-width open mudflats grading into native *Spartina* marsh, with some pickleweed/gumplant (*Grindelia stricta*) marsh at higher elevations. All sloughs and marshes are bordered by levees topped by access roads or the Bay Trail. Residential areas border both Steinberger and Belmont Sloughs just inland of the levees, and include community walking trails. A newly breached marsh at North Point on the right bank of Belmont Slough at the mouth has already been invaded by hybrid *Spartina* and will need to be included in future monitoring and treatment. Airboat will be used on this site for the first time in 2012, a welcome improvement over amphibious tracked vehicles in the very soft mud at the mouth. Some support from backpack sprayers will likely be employed at the upper elevation zones where this method would be more efficient.

SFO. This Type IV site around the perimeter of San Francisco International Airport (SFO) includes seven distinct edges with varying degrees of marsh development based on exposure and accretion, totaling approximately 25 acres. There are two large runway strips that jut out into the bay, the longer running roughly southeast to northwest with the shorter strips running perpendicular. The largest area of marsh is adjacent to the runways along the southern shoreline of SFO, just east of Hwy. 101 in Millbrae. This protected cove has accreted substantial sediment and has prograded marsh out as much as 200 m from the concrete and fill. At the Millbrae Avenue security gate to the runways, a large culvert empties a concrete flood control channel that draws stormwater from the airport complex. Two other areas of minimal pickleweed marsh have developed, one on the northeast side of the junction of the two runway strips and the other just south of Seaplane Harbor to the northwest of the shorter runways at the end of the N. Access Road. Both of these face the open bay, and hence are subject to greater wave energy resulting in less accretion. The site will be treated by a combination of airboat and backpack sprayer.

San Pablo Marsh. This Type I site is a 165-acre marsh at the mouth of San Pablo Creek on the City of Richmond shoreline in southeastern San Pablo Bay. San Pablo Marsh has an extensive pickleweed marsh plain, with *Grindelia* lining the banks of the channels and a *S. foliosa* fringe on the bayfront as well as in the channels. The marsh stretches east to an 11-acre pickleweed, *S. foliosa* and alkali bulrush (*Bolboschoenus maritimus*) cove bordered by levees on either side, located behind the Richmond Rod and Gun Club rifle range. The western portion of this site has been treated since 2005, but the larger infestation in the eastern marsh and out onto the mudflats has evaded treatment until recently due to early senescence. The mudflat clones, as well as the infestation encroaching up the channels, were first treated by airboat and backpack in 2008. Efficacy has been very high on the mudflat clones and in the upper channels, but the established heavy infestation along the fringe has taken longer to control, and a portion was not permitted for treatment in 2011 and subsequently was allowed to rebound and expand. Airboat and backpack sprayers will be used again at this site in 2012.

***Oakland Inner Harbor*.** This Type IV site consists of the armored shoreline and marinas of the Oakland Inner Harbor from the old Alameda Naval Air Station south to the High Street Bridge. Treatment throughout these scattered sites on the Alameda and Oakland shorelines began in 2007, with the majority of the work done from a shallow-bottom boat with support from backpacks in areas with no access from the water. This same approach will be used for 2012 treatment on the remaining small patches and scattered plants.

Palo Alto Baylands. This Type II site is part of a 1,940 acre nature preserve and park complex, one of the largest tracts of undisturbed marshland remaining in San Francisco Bay, owned by the City of Palo Alto and located on the western bayfront approximately 2.5 miles south of the Dumbarton Bridge. The site is located east of Hwy. 101 at the end of Embarcadero Road, and includes those areas south of San Francisquito Creek and north of Charleston Slough. Within the site, Harriet Mundy Marsh is a peninsula vegetated with pickleweed (*Sarcocornia pacifica*), *S. foliosa*, and gumplant (*Grindelia stricta*) that extends out to Sand Point from the main parking area. There is a restored marsh cove to the southwest of the parking area that was once home to a yacht club before it was allowed to silt in and return to marshland. The water quality sample will be taken from the most infested area of the site, Hooks Island, which is located just offshore from Mayfield Slough and contains a heavily channelized pickleweed marsh with large areas of *S. foliosa*. The site will be treated in 2012 by truck and hose for dense areas between the mainland and island, with backpack sprayers used for the remainder (including some island areas in the southwest only accessible by boat).

***Greco Island South*.** Greco Island is reported to be the largest remaining prehistoric tidal marsh in the South Bay with a total area of 817 acres (Greco Island North sub-area covers 556 acres while Greco Island South is 261 acres). This Type I site is located immediately southeast of Bair Island across the mouth of Redwood Creek and approximately one mile northwest of the western landfall of the Dumbarton Bridge at Ravenswood. The southern shoreline borders West Point Slough and the remaining salt ponds of Redwood City as well as Bayfront Park in Menlo Park. The northern shore on the open bay is comprised of wide mudflats receiving flow from many small, shallow sloughs filled with native *Spartina* that continue up onto the pickleweed marsh plain. The southeastern lobe of Greco contains more plant diversity and a large population of clapper rails, with many sinuous channels heavily lined with *Grindelia* after being freed from competition with the hybrid *Spartina* meadows present at the inception of ISP treatment. The channels in the northwestern lobe are currently being enhanced with *Grindelia* by ISP to create better clapper rail habitat and increase the carrying capacity over the entire island. The site will be treated with a combination of airboat and backpack sprayer in 2012.

Giant Marsh. Giant Marsh is a 30-acre pickleweed marsh in the far southwestern corner of Point Pinole Regional Shoreline on San Pablo Bay. The infestation at Giant Marsh is composed of scattered clones of hybrid *Spartina alterniflora* along the bayfront edge of the marsh and out onto the mudflats. This infestation was in the very early stages of establishment (less than an acre) before treatment began, and had not yet colonized the interior of the marsh nor established much along the network of manmade channels. This Type II site was treated for the first time in 2008 and the remaining infestation will be treated in 2012 using backpack sprayers. Since the infestation at this site is almost exclusively within the fringe of *S. foliosa*, identification of cryptic hybrids has been challenging and has extended the length of time needed to gain control of the infestation.

Seal Slough. This Type I site is located in the City of San Mateo on its eastern border with Foster City. The site begins 200m upstream of the bridge crossing of J. Hart Clinton Drive spanning the slough channel, at tide gates that restrict water exchange and transform the upstream slough into the sinuous, 6km-long Marina Lagoon that is lined with residential properties. The portion of the site downstream of the tide gates is characterized by large mudflats that have accreted in the absence of scour from the full volume of the slough. On the downstream side of the bridge to the north, the mouth of the waterway opens to a 300m-wide cove bordered by a 70-acre tidal marsh to the east and the large hillside of Shoreline Park to the west above a heavily armored bank. The marsh contains small channels, mudflats, pans, mid-marsh pickleweed (*Sarcocornia pacifica*) and some gumplant (*Grindelia stricta*) stands, sand/shell beach berms along most of the bayfront, and PG&E power line towers anchored in the western marsh edge at the mouth. In 2006, CalTrans began a mitigation project by excavating a somewhat sinuous channel to the bay in the southeastern corner of the marsh, and the fresh substrate along the banks was quickly infested from the neighboring site. There is an upland berm running north/south in the middle of the site that serves to divide the older marsh from this mitigation site. The central portion of the marsh at the mouth of Seal Slough was not permitted for treatment in 2011, and subsequently was allowed to rebound and expand. Airboat will replace amphibious tracked vehicle as the primary treatment method at the site, while crews with backpack sprayers will complete the rest of the work.

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 ISP 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 onto 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 may be 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 6**).

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