San Francisco Estuary Invasive *Spartina* Project

2005 Water Quality Monitoring Report

Prepared for

San Francisco Estuary Invasive *Spartina* Project
A Project of the State Coastal Conservancy
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Submitted to

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1. Executive Summary

In 2005, 78 locations in the San Francisco Bay were treated with herbicides as part of the invasive *Spartina* control effort, planned and implemented by the Invasive *Spartina* Project. Thirteen of these sites were monitored for water chemistry and conventional water quality parameters to satisfy herbicide permit requirements by the State Water Resources Control Board. Samples were collected at the treatment sites prior to, immediately after, and one week after the application. The results for conventional water quality parameters (temperature, dissolved oxygen, electrical conductivity, and pH) showed no significant changes ($p > 0.05$) over the sampling period of seven days. The averages of measurements at all sites were very similar before, during, and after the treatment with glyphosate and imazapyr. Detectable concentrations of imazapyr (0.5 - 40 µg/L) and glyphosate (30,000 µg/L) were found after treatment at all 13 monitored sites occurred. Imazapyr concentrations at all sites were below any reported acute or chronic effect concentrations for aquatic wildlife. Glyphosate concentrations at one monitored site were high but below toxicity thresholds for fish and most invertebrates.

2. Background

2.1 Non-native Spartina in San Francisco Bay

The invasive *Spartina alterniflora* (Atlantic cordgrass) grows in the intertidal zone where it colonizes mudflats or sandflats in brackish or saline water and invades mid-marsh pickleweed plains and tidal channels in San Francisco Bay. After hybridizing with the native form, *Spartina foliosa* (Pacific cordgrass), an even more vigorous form was developed that extensively invades salt marshes and tidal flats causing a significant loss of wetland habitat. In its native range, in the Atlantic and Gulf coasts of North America, *S. alterniflora* typically dominates low salt marshes. It was introduced to the Pacific Coast of the U.S. for erosion control around 1940 (Marchant 1970; Hitchcock 1971). Now *S. alterniflora* and its hybrids are commonly found in the San Francisco Bay, and dense stands of vegetation threaten the habitat of resident and migrating shorebirds and waterfowl (Sayce 1988). Additionally, it clogs up channels and sloughs and outcompetes native plant species resulting in reduced biodiversity in the marsh.

2.2 Spartina Control with Herbicide

The Invasive *Spartina* Project, established by the California State Coastal Conservancy, is dedicated to controlling the spread of *Spartina* in San Francisco Bay marshes, sloughs, and channels. This is achieved by surveying, characterizing, and mapping all areas of infestation and organizing herbicide applications. Timing of herbicide applications is chosen to protect endangered species during their breeding season while having a maximum impact on the invasive plants. One-hundred and thirty-four sites were selected in 2005 for potential herbicide treatment. Aquamaster™ (glyphosate) and Habitat™ (imazapyr) are the presently the only registered herbicides for *Spartina* control in California.

2.3 State Regulatory Requirements

Under current state regulations (State Water Resources Control Board Water Quality Order No. 2004-0009-DWQ), permits are required for all aquatic pesticide applications discharging pollutants into waters of the United States. Water quality monitoring for herbicides applied within the Invasive *Spartina* Project and ancillary measurements were conducted by the San Francisco Estuary Institute (SFEI) to satisfy National Pollutant Discharge Elimination System (NPDES) permit compliance monitoring requirements. Thirteen sites were sampled up to 24 hours prior to the herbicide application, immediately after the application, and one week after the application.

2.4 Water Quality Monitoring Plan

The San Francisco Estuary Institute prepared the Water Quality Monitoring Plan (WQMP) for the Invasive *Spartina* Project, which was submitted to the Regional Water Quality Control Board in Section 9 of the 2005 Aquatic Pesticide Application Plan (APAP).

2.4.1 Selection of WQ Monitoring Sites

One-hundred and thirty-four sites throughout the San Francisco Bay region were identified with *Spartina* infestations and listed for potential treatment within the *Spartina* control effort for 2005. These sites were divided into four distinct types (listed below) to allow sampling from each site type. According to current permit regulations, 10% of all sites receiving herbicide application must be monitored for potential water quality impacts. Based on the initial APAP that was generated prior to the *Spartina* treatment season, 13 sites were selected for the WQMP to represent different retention times for herbicides in different types of estuarine environments in San Francisco Bay. The monitored sites and the assigned environment types are listed in Table 1.

Site Types:

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 13 monitoring sites include three type I sites, four type II sites, three type III sites, and three type IV sites. Three of the sites monitored are located on the Bair-Greco Island Complex, along the west-side of San Francisco Bay, immediately north of the Dumbarton Bridge, in San Mateo County. Type I, II, and III sites are present in this area. Further north, an additional five monitoring sites are located north of Foster City, in San Mateo County. These five sites comprise environments of all four site types.
On the east-side of San Francisco Bay, near the mouth of San Lorenzo Creek, a type II site was selected in Oro Loma Marsh, in Alameda County. Additional sites are located further south at the Old Alameda Creek and at the Alameda Flood Control Channel, comprising type II and III sites. Located in the Alameda-San Leandro Bay (Alameda Shoreline), a type I site was selected to represent a balanced number of sites in all environment types.

All 13 sites were described in the WQMP, including type of infestation, size of impacted area and site characteristics. Maps of the monitored sub areas are displayed in Figure 1a, 1b, and 1c. The detailed site description can also be found in Appendix A of this report.

Table 1. Thirteen sampling sites monitored for the Invasive *Spartina* Project. (Argo = amphibious all-terrain, off-road vehicles.)

Sites	Type	Application	Site Number
Bair Island/B2 North Quadrant	I	Imazapyr - Helicopter	2d
Steinberger Slough	II	Imazapyr - Argo	2b
North Steinberger Mouth	III	Imazapyr - Argo	2a
Oro Loma Marsh East	II	Glyphosate - Truck	7a
Alameda Shoreline/Elsie Roemer	I	Imazapyr - Truck	17a
Old Alameda Creek (OAC)	III	Imazapyr - Helicopter	13a
Upper Alameda Flood Control Channel	III	Imazapyr - Helicopter	1b
Lower Alameda Flood Control Channel	II	Imazapyr - Helicopter	1c
Near Sanchez Marsh	IV	Imazapyr - Argo	19k
Fisherman's Park	II	Imazapyr - Argo	19m
San Mateo Creek Mouth/Ryder Park	II + IV	Imazapyr - Argo	19o
Coyote Point Marina Outer Harbor	I	Imazapyr - Argo	19n
Coyote Point Marina Inner Harbor	IV	Imazapyr - Argo	19n

Figure 1a. Location of treatment sites 7a and 17a selected for water quality monitoring.

Figure 1b. Location of treatment sites 13a, 1b, and 1c selected for water quality monitoring.

Figure 1c. Location of treatment sites 19k, 19m, 19n, 19o, 2a, 2b, and 2d selected for water quality monitoring. Note that two monitoring sites are located at Coyote Point Marina.

2.4.2 Sampling Plan

The monitoring events were tailored to characterize the potential risk involved with glyphosate and imazapyr applications. Following permit requirements, the monitoring conducted included background monitoring collected between 1 and 24 hours prior to the application, application event monitoring, and post-application event monitoring. The application event samples were collected adjacent to the treatment area after sufficient time had elapsed for treated water to enter the adjacent area. The post-application event samples were taken from the downstream edge of the treatment area one week after application. One field blank and one sample duplicate were collected from each sampling event. Additionally, conventional water quality parameters were measured to evaluate potential impacts of herbicide applications to the surrounding water column.

3. Applied Herbicides

Seventy-eight sites were treated with herbicides in September and October of 2005. The sites monitored within the WQMP therefore represent 17% of all sites that received herbicide application as part of the Invasive *Spartina* Project. Since not all 134 sites that were initially identified with *Spartina* infestations and listed for potential treatment in the APAP received herbicide applications, the water quality samples collected exceed the required 10% of treatment sites to be monitored for the general NPDES permit. Table 2 summarizes treatment information on all monitored sites.

3.1 Imazapyr

Habitat® was registered for use in aquatic systems in California on August 30, 2005. Habitat® (with the active ingredient imazapyr) is a broad-spectrum, non-selective, slow-acting systemic herbicide that is absorbed by the leaves and roots. It accumulates in the meristem region, and disrupts DNA and protein synthesis of the plants (Leson & Associates 2005). It is manufactured by BASF Corporation (Research Triangle Park, North Carolina). Habitat® was applied at all but one of the monitored sites between September 9, 2005 and October 22, 2005.

3.2 Glyphosate

Aquamaster® (with the active ingredient glyphosate) is also a broad-spectrum, nonselective, systemic herbicide used for control of annual and perennial plants including grasses, sedges, broad-leaved weeds, and woody plants (Kidd 1991). Aquamaster® is manufactured by Monsanto Company (St. Louis, Missouri). It was applied at one monitoring site in the Oro Loma Marsh on September 8, 2005.

3.3 Adjuvants

Adjuvants are added to the spray tank mixture of the herbicide to enhance the efficacy of the active ingredient or to minimize adverse effects to water quality. Since the leaves of the treated plants in San Francisco Bay are covered with salt and sediment, absorption of the herbicide is difficult to achieve and the use of surfactants plays an important role in the application process. The non-ionic spray adjuvants Liberate® and Cygnet Plus®, as well as the esterified seed oil Competitor® were used in the herbicide mixture as surfactants. Liberate® is manufactured by Loveland Industries Inc. (Greeley, Colorado) and is composed of soy oil derivatives. Cygnet Plus® is manufactured by Brewer International, Inc. and is composed of emulsifiable methylated vegetable oils. Competitor is manufactured by Wilbur Ellis Company (San Francisco, California) and is comprised of oleic acid, ethyl ester, and polyoxyethylene dioleate. Since these adjuvants do not contain nonylphenol ethoxylate, a component of some surfactants (e.g., R-11) that is suspected of causing endocrine disruption in aquatic organisms, chemical concentration analysis was not required by the general NPDES permit. The herbicide mixture also sometimes contained Blazon®

as a blue spray pattern indicator, which is manufactured by Milliken Chemical in Inman, South Carolina.

3.4 Application Rates and Methods

- *Upper and Lower Flood Control Channels and Old Alameda Creek:*
  6 pints of Habitat®/acre plus 2 pints of either Liberate® or Competitor® were used per 15 gallons of herbicide mixture for helicopter applications.
- *Alameda Shoreline/Elsie Roemer:*
  6 pints of Habitat®/acre, 2 pints of Cygnet Plus®/ acre, 1 pint of Blazon®/acre, and 2 pints of Stay Put®/acre as a deposition and drift control agent were used for truck applications.
- *Steinberger Slough, North Steinberger Mouth, and Bair Island/B2North Quadrant:*
  6 pints of Habitat®/acre, 2 pints of Competitor®/acre, and 1.5-2 pints of Blazon®/acre were used for helicopter applications and for ground applications with argos (amphibious all-terrain, off-road vehicles).
- *West Bay Region (including San Mateo Creek, Coyote Point Marina Inner and Outer Harbor, Fisherman's Park, and Near Sanchez Marsh):*
  6 pints of Habitat®/acre, 2 pints of Competitor®/acre, and 1.5-2 pints of Blazon®/acre were used for ground applications with argos.
- *Oro Loma Marsh:*
  5 gallons of Aquamaster® and 2 pints of Competitor® were mixed with 1-2 pints of the blue dye Blazon® for ground applications by truck in a 100 gallon herbicide mixture.

Table 2. Herbicide application methods and times. All sites were treated with imazapyr except Oro Loma Marsh, which was treated with glyphosate. (* glyphosate site.)

Sites	Date	Application Time (Start)	Method
North Steinberger Mouth	9/14/2005	9:00	Argo
Steinberger Slough	9/14/2005	9:30	Argo
Oro Loma Marsh East*	9/8/2005	7:00	Truck
Bair Island/B2 North Quadrant	9/9/2005	8:00	Helicopter
San Mateo Creek	9/14/2005	11:00	Argo
Coyote Point Marina Inner Harbor	9/14/2005	12:00	Argo
Coyote Point Marina Outer Harbor	9/14/2005	11:30	Argo
Fisherman's Park	9/14/2005	13:45	Argo
Near Sanchez Marsh	9/14/2005	14:30	Argo
Alameda Shoreline/Elsie Roemer	9/19/2005	8:00	Truck
Lower Flood Channel	9/22/2005	11:30	Helicopter
Upper Flood Channel	9/22/2005	11:30	Helicopter
Old Alameda Creek	9/22/2005	8:00	Helicopter

4. 2005 Water Quality Sampling

4.1 Sampling Locations

Sampling sites were selected to represent the environment types described in the Invasive *Spartina* Project APAP for all subareas that were treated (Figure 2). Sampling sites were also chosen to achieve safe access for the sampling team.

Figure 2. Map of all sampling locations in the San Francisco Bay. See Appendix 1 for information on latitudes and longitudes of sampling sites.

4.2 Sampling Events

All pre application samples were collected 1-24 hour prior to the treatment. In some cases (e.g., Bair Island, Oro Loma Marsh), the application had already started at a different point of the treatment area while the sampling team was still collecting the sample at the site selected for water quality monitoring. However, the fact that there was no detectable herbicide concentration measured in the pre application samples at those sites suggest that there was no spray or drift that interfered with the samples collected.

Application samples were collected 1-6 hours after the treatment (Table 3), depending on tidal cycle (enough time had to pass for site water to mix with Bay water) and accessibility to the area. Interference with applicators' work and equipment was avoided, and especially during helicopter applications, the area had to be cleared before samples were collected by SFEI. After treatment at Coyote Point Marina on September 13, 2005, the Mosquito Abatement District application team split up due to time constraints and sent one manned argo further north to cover isolated *Spartina* patches at Fisherman's Park and Near Sanchez Marsh. For these sites, the SFEI sampling team was able to accompany the argo and to collect the pre and the application samples immediately before and following the brief treatment periods in the selected areas.

All post application samples were collected six to seven days after the treatment had occurred. Since scheduling problems or site access did not have to be negotiated for this sampling event, all samples were collected without any difficulties.

Table 3. Sampling events for all treated sites.

Sites	Pre	Time	Application	Time	1 Week Post	Time
North Steinberger Mouth	9/13/2005	15:20	9/14/2005	10:52	9/20/2005	11:07
Steinberger Slough	9/13/2005	14:42	9/14/2005	11:18	9/20/2005	11:03
Oro Loma Marsh East	9/8/2005	7:36	9/8/2005	12:33	9/15/2005	12:41
Bair Island/B2 North Quadrant	9/9/2005	8:13	9/9/2005	9:43	9/15/2005	11:20
San Mateo Creek	9/13/2005	8:36	9/14/2005	12:22	9/20/2005	11:52
Coyote Point Marina Outer Harbor	9/13/2005	9:50	9/14/2005	13:09	9/20/2005	12:27
Coyote Point Marina Inner Harbor	9/13/2005	9:25	9/14/2005	12:54	9/20/2005	12:20
Fisherman's Park	9/14/2005	13:41	9/14/2005	13:58	9/20/2005	12:56
Near Sanchez Marsh	9/14/2005	14:28	9/14/2005	14:41	9/20/2005	13:14
Alameda Shoreline/Elsie Roemer	9/18/2005	13:49	9/19/2005	13:05	9/26/2005	12:46
Lower Flood Channel	9/21/2005	13:05	9/22/2005	15:08	9/29/2005	13:35
Upper Flood Channel	9/21/2005	12:43	9/22/2005	14:41	9/29/2005	12:59
Old Alameda Creek	9/22/2005	6:37	9/22/2005	15:58	9/29/2005	12:17

4.3 Sampling Procedures

Samples were collected using sampling procedures developed for the State Water Resources Control Board (SWRCB) Aquatic Pesticide Monitoring Program (APMP). All procedures are outlined in the 2004 APMP Quality Assurance Program Plan (QAPP).

The QAPP (Yee et al. 2004) can be found at
http://www.sfei.org/apmp/reports/APMP2003QualityAssur.pdf

4.3.1 Field Equipment

Container preparation included non-phosphate detergent washing, multiple tap water and ASTM Type I de-ionized water rinses, and 1:1 HNO_3 (nitric acid) rinses. Containers were oven dried. All containers met and exceeded the required detection limits established by the USEPA in Specifications and Guidance for Contaminant-Free Sample Containers (USEPA 1992).

Water samples were collected using a portable peristaltic pump, and samples were then stored in pre-cleaned High Density Polyethylene (HDPE) bottles. The pump tubing was cleaned before each sampling day with methanol and de-ionized water. On days with consecutive sampling events, the tubing was rinsed with de-ionized water between sites. Both ends of the tubing were covered with foil to protect them from contamination when not in use. Temperature, electrical conductivity, salinity, pH, and dissolved oxygen were measured with a portable multimeter Multi 340i Sensor (Wissenschaftliche-Technische Werkstaetten GmbH & Co. KG, in Germany). Turbidity was measured with a field turbidimeter (Hach, Model 2100P).

4.4. Sampling Analysis

Following collection, water samples were stored on ice and shipped to the California Department of Fish and Game Water Pollution Control Laboratory on the same day by overnight delivery. The samples were analyzed for imazapyr concentration and hardness within the appropriate holding times (extracted within seven days, analyzed within 21 days of extraction for imazapyr). The analytical method used for imazapyr was Liquid Chromatograph/Mass Spectrometer – Atmospheric Pressure Ionization-ElectroSpray. For the analysis of hardness, EPA method 130.1 was used.

Glyphosate samples were also analyzed by the California Department of Fish and Game using EPA method 547 (High Performance Liquid Chromatography with post column derivatization using orthophthalaldehyde (OPA) and fluorescence). Samples were analyzed within 14 days (maximum holding time for glyphosate samples prior to extraction). The analytical laboratory adhered to all QA requirements outlined in the APMP QAPP (Yee et al. 2004).

Statistical analysis of treatment site results for ancillary data was performed using one way analysis of variance (ANOVA). One way ANOVA was performed with each chemical parameter being evaluated as a function of the sampling events to measure an overall significant difference over the three sampling dates.

5. Results and Discussion

5.1 Imazapyr

The concentrations of imazapyr in water varied from non-detect (method detection limit 0.02 µg/L) to 40 µg/L. Non-detectable concentrations were sampled at all but three sites before and one week after the treatment. The highest concentration, of 40 µg/L, was sampled immediately after application at the inner harbor of Coyote Point Marina. In general, sites that received aerial herbicide applications showed consistently lower concentrations (< 5 µg/L, N = 4) compared to ground applications by truck or argo. Further differences in imazapyr concentrations measured immediately after the application were most likely caused by the time difference it took for Bay water to mix with the sampling water. For example, the inner harbor of Coyote Point Marina is secluded from the Bay and turn-over rate for water in this area is longer than at the bay front of Sanchez Marsh, where the lowest application concentrations were measured.

The observed concentrations were all far below any reported toxicity levels for aquatic life. Rainbow trout *(Oncorhynchus mykiss)* 96-hour lethal concentrations (LC_{50}) are reported at 22,305 mg/L for the technical grade herbicide (King et al. 2004). Herbicide mixtures with non-ionic surfactants can reduce the LC_{50} value to 113 mg/L (113,000 µg/L) for the same species (Smith et al. 2002). Additional information on the toxicity of imazapyr can be found in Leson & Associates 2005.

Figure 3 shows all imazapyr concentrations in water at all sites over the sampling period. The increase of herbicide concentrations displayed in the graph was measured within approximately 1-6 hours after the application. Within a week following the imazapyr application, concentrations at 75% of the sites returned to non-detect. Only three out of 13 sites still showed detectable concentrations. Two of them, North Steinberger Mouth and Steinberger Slough, were retreated by the San Mateo County Mosquito Abatement District due to a communication problem five days after the first application, and the elevated concentrations were a result of the one week post sample actually being collected one day after the second application. These two unintended results show that the imazapyr concentrations at the treated sites are reduced to relatively low concentrations within 24 hours. The third site, at Fisherman's Park, was not re-treated but had shown 0.2 ug/L of imazapyr in the pre sample, collected immediately before the application. There were no known imazapyr applications near this site on that day; however, post-treatment samples had been collected at other sites one hour prior to pre-treatment sampling at Fisherman's Park, so it is possible that cross-contamination between sites may have occurred. It is also possible that the sample may have detected imazapyr applied by some non-Spartina Project source.

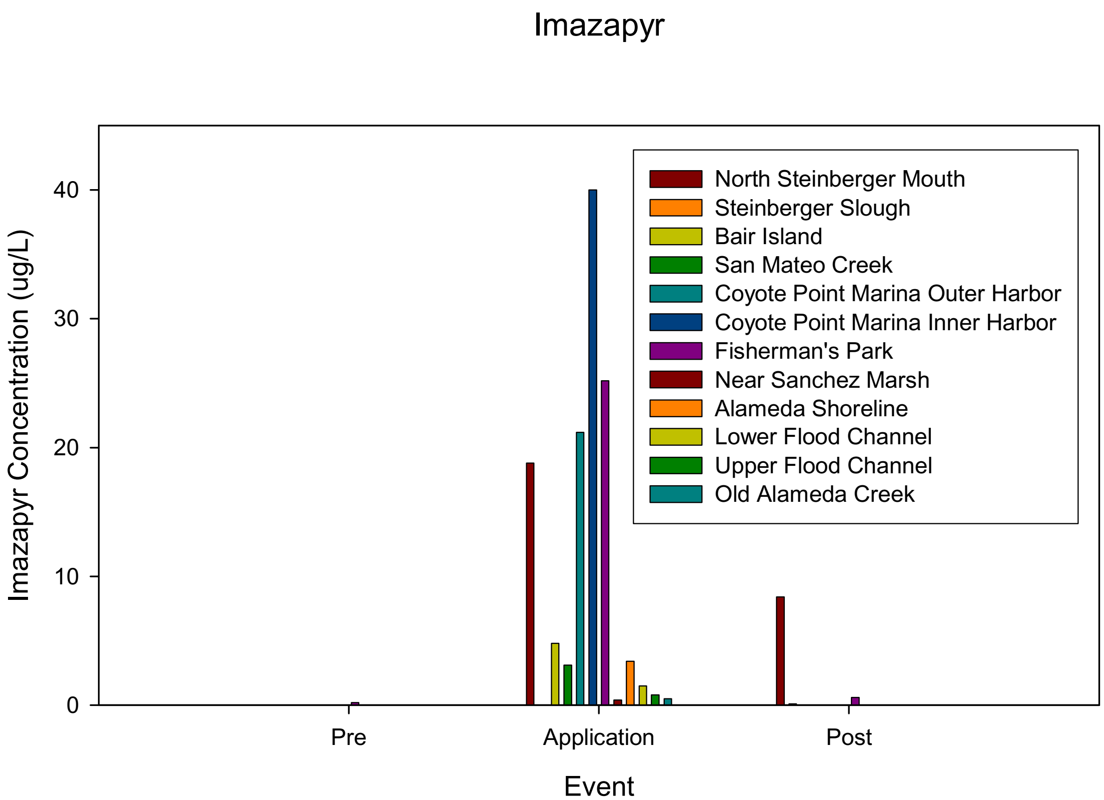

Figure 3. Concentrations of imazapyr at all individual sites over the sampling period.

5.2 Glyphosate

Concentrations of glyphosate and the metabolite, aminomethylphosphonic acid (AMPA), were measured at the Oro Loma Marsh site only. The herbicide and the metabolite concentrations went from non-detect (method detection limit 5 and 10 µg/L, respectively) to 30,000 µg/L (i.e., 30 mg/L) for glyphosate and 765 µg/L for AMPA immediately after treatment. The post application sample, one week later, had no detectable concentrations for glyphosate or AMPA. Because of the high concentration, the application sample was re-analyzed by the laboratory on request of SFEI. The new result as well as the original duplicate of the sample showed very similar concentrations (94% RPD). The LC_{50} values for rainbow trout are reported at 86 mg/L for glyphosate and 520 mg/L for AMPA (Giesy et al. 2000, Weed Science Society of America 1994). Glyphosate is slightly toxic to aquatic invertebrates, and the reported LC_{50} for Atlantic oysters is 10 mg/L (Weed Science Society of America 1994). The glyphosate concentration in this study exceeded the LC_{50} for aquatic invertebrates. The application sample was collected approximately two hours after the treatment in that area was completed (Table 2 and 3) and approximately three hours after the morning low tide occurred on September 8th, 2005. Incoming tidal surface water was already well mixed with the treatment water when the sample was collected. The high concentration may have been caused by poor mixing in the tank before herbicide application.

5.3 Conventional Water Quality Parameters

Water quality results for all ancillary measurements showed only slight changes over the sampling period of seven days at all sites (Table 4). Average concentrations for dissolved oxygen, pH, electrical conductivity, salinity, and turbidity prior to the herbicide applications were similar to the concentrations directly after the herbicides were applied, as well as one week after the spraying occurred (Figure 4). One way ANOVA indicated no significant change in water quality parameters over the treatment period (DO: p-value > 0.2, pH: p-value > 0.5, EC: p-value > 0.6, turbidity: p-value > 1.0, salinity: p-value > 0.5). This suggests that the chemical application of neither imazapyr nor glyphosate had an impact on these parameters at the monitored sites in San Francisco Bay. It is possible that potential water quality impacts of herbicide applications or the subsequent decomposition of plant material is minimal in San Francisco Bay due to the total water turnover of the system.

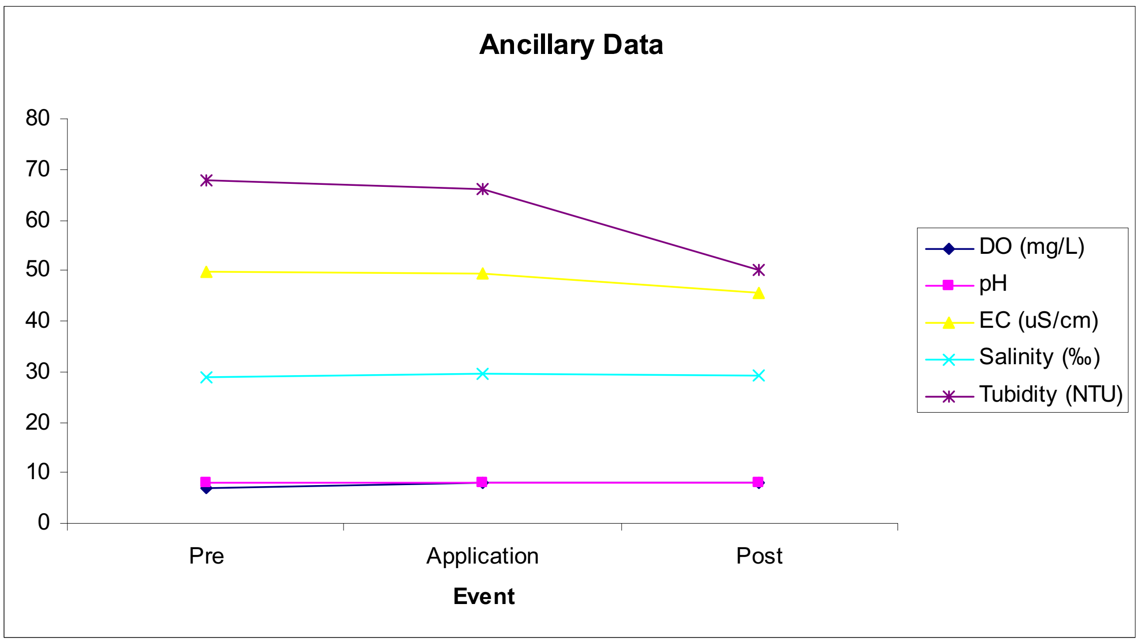

Figure 4. Average of ancillary data collected with water samples for herbicide analysis at all sites.

Dissolved Oxygen (DO)

Dissolved oxygen concentrations varied from 2.6 mg/L at Bair Island to 10.4 mg/L at the outer harbor of Coyote Point Marina, the lower concentration measured during the pre sampling event and the higher concentration measured during the one week post sampling event. Within this range, concentration fluctuated without exhibiting any significant patterns at the 13 sites. A change in dissolved oxygen concentrations due to the herbicide applications is therefore unlikely.

Electrical Conductivity (EC)

The EC varied from 41.6 µS/cm at the Upper Alameda Flood Control Channel site to 94.4 µS/cm at the Bair Island site. Measurements throughout the sampling period were fairly consistent and did not exhibit any significant changes associated with the chemical treatment.

Turbidity
Turbidity values varied widely from 4 NTU at Coyote Point Marina to over 1,000 NTU at the Near Sanchez Marsh site. This sample was collected at the Bay front east of Sanchez Marsh where isolated patches of *Spartina* were treated. The fluctuation exhibited no consistent change in turbidity after the treatment period.

Hardness
Water hardness concentrations varied from 4,780 mg $CaCO_3$/L at the Old Alameda Creek site to 14,200 mg $CaCO_3$/L at the Bair Island site (Figure 5). Water hardness describes the presence of certain minerals in the water column, and studies have shown that high calcium and magnesium concentrations in water can reduce the effectiveness of pesticides when hardness is above 150-300 mg/L in source water for pesticide mixtures (Boerboom 2001). This suggests that at the treatment sites (hardness average of 5,780 mg $CaCO_3$/L) bioavailablity of pesticides is likely reduced in the ambient water.

Herbicides, especially glyphosate, are also known to be very susceptible to inactivation by silt and organic matter. These parameters were not measured in this study but measured turbidity peaks suggest that this may have occurred. Since all sites are located within the San Francisco Bay and are subject to tidal cycles, a high content of organic matter and relatively high turbidity measurements were observed at several sites.

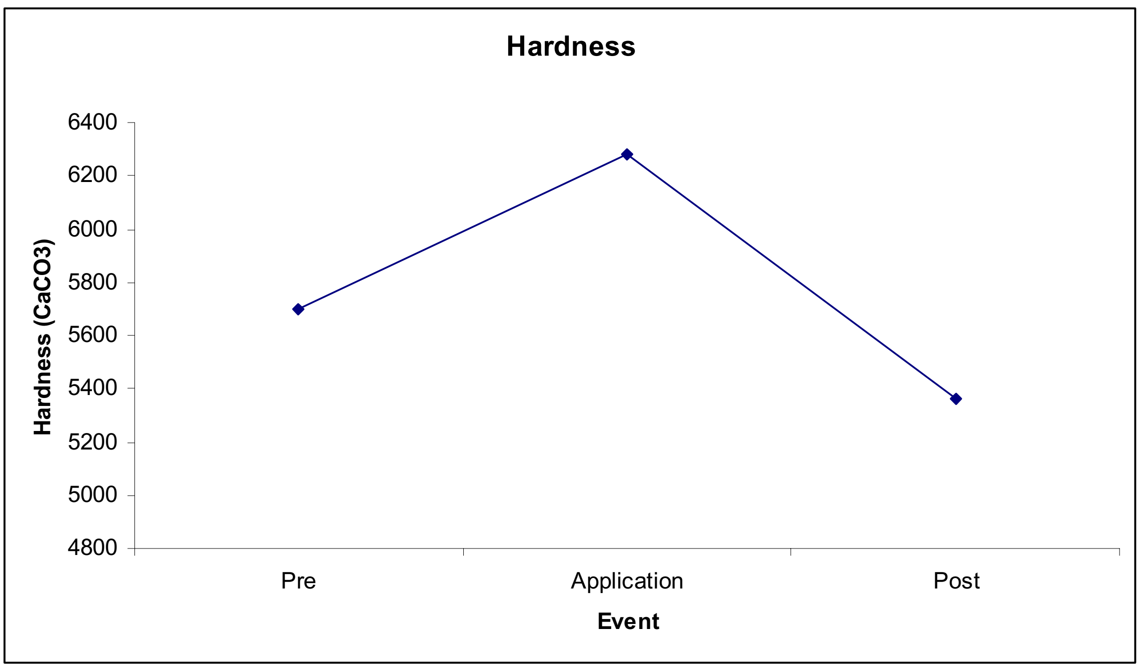

Figure 5. Average of water hardness concentrations before, during, and after herbicide application at all sites.

Table 4. All results sampled over three sampling events. DO = dissolved oxygen, EC = electrical conductivity, *AMPA = Aminomethylphosphonic acid (Glyphosate metabolite), † = sample bottle broken during shipment, ND = non-detect.

Station	Event	Water Temp.	DO	pH	EC	Salinity	Turbidity	Glyphosate	AMPA*	Imazapyr	Hardness
		C	mg/L	s.u.	uS/cm		NTU	ppb (ug/L)	ppb (ug/L)	ppb (ug/L)	$CaCO_3$ mg/L
North Steinberger Mouth	Pre	21.3	NA	8.2	44.4	28.5	49.3			ND	5,360
Steinberger Slough	Pre	22.9	NA	8.1	48.9	28.2	8.3			ND	5,420
Oro Loma Marsh	Pre	16.1	3.6	7.3	43.8	27.8	157.0	ND	ND		5,620
Bair Island	Pre	16.0	2.6	7.7	94.4	NA	102.0			ND	13,800
San Mateo Creek	Pre	15.0	6.0	8.0	47.0	29.9	9.5			ND	5,900
Coyote Point Marina Outer Harbor	Pre	15.9	5.2	7.5	47.3	30.2	232.0			ND	†
Coyote Point Marina Inner Harbor	Pre	18.3	5.7	8.1	47.0	30.2	5.3			ND	5,850
Fisherman's Park	Pre	20.1	10.2	8.2	46.7	30.1	104.0			0.2	5,900
Near Sanchez Marsh	Pre	21.1	8.4	8.1	46.9	30.1	>1,000			ND	5,850
Alameda Shoreline	Pre	18.4	8.8	8.1	45.5	29.0	48.1			ND	5,360
Lower Flood Channel	Pre	25.4	10.2	8.2	44.3	28.6	15.4			ND	5,240
Upper Flood Channel	Pre	19.9	7.0	8.3	44.3	27.5	51.3			ND	5,080
Old Alameda Creek	Pre	16.1	7.8	8.1	46.0	26.8	31.1			ND	4,780
North Steinberger Mouth	Application	17.0	6.6	8.1	44.3	28.2	28.8			18.8	5,500
Steinberger Slough	Application	18.3	8.9	8.2	44.0	28.0	10.5			†	5,400
Oro Loma Marsh	Application	23.3	8.1	8.0	45.3	29.3	47.5	30,000	765		5,540
Bair Island	Application	16.9	3.2	7.6	94.3	NA	99.3			4.8	14,200
San Mateo Creek	Application	17.1	7.1	8.0	47.0	30.1	65.1			3.1	6,050
Coyote Point Marina Outer Harbor	Application	18.5	8.2	8.0	47.1	30.2	174.0			21.2	6,100
Coyote Point Marina Inner Harbor	Application	19.2	8.6	8.2	46.8	30.1	6.6			40.0	5,800
Fisherman's Park	Application	20.1	9.6	8.2	46.7	30.1	290.0			25.2	6,000
Near Sanchez Marsh	Application	20.9	8.4	8.1	46.9	30.2	>1,000			0.4	5,750
Alameda Shoreline	Application	21.6	8.6	8.2	45.6	29.4	3.8			3.4	5,440
Lower Flood Channel	Application	23.9	9.4	8.1	46.5	30.3	15.1			1.5	5,360
Upper Flood Channel	Application	19.9	8.6	8.1	44.2	28.4	30.7			0.8	5,200
Old Alameda Creek	Application	20.0	9.9	8.2	45.3	29.4	19.7			0.5	5,360
North Steinberger Mouth	Post	25.3	7.9	8.1	46.0	29.9	>1,000			8.4	5,420
Steinberger Slough	Post	20.7	7.7	8.0	43.7	28.0	43.5			0.1	5,180
Oro Loma Marsh	Post	17.7	9.6	7.9	45.0	28.8	46.8	ND	ND		5,340
Bair Island	Post	17.1	7.1	8.0	44.1	28.0	13.0			ND	5,260
San Mateo Creek	Post	23.1	8.8	8.1	47.0	27.8	164.0			ND	5,580
Coyote Point Marina Outer Harbor	Post	22.5	10.4	8.2	47.4	30.7	41.7			ND	5,620
Coyote Point Marina Inner Harbor	Post	20.3	9.3	8.2	46.9	30.2	3.7			ND	5,560
Fisherman's Park	Post	22.2	9.0	8.1	46.2	29.8	38.6			0.6	5,400
Near Sanchez Marsh	Post	20.4	8.6	8.2	47.3	30.5	55.3			ND	5,480
Alameda Shoreline	Post	19.5	10.2	8.1	45.9	29.5	68.1			ND	5,380
Lower Flood Channel	Post	23.2	8.2	8.1	46.1	29.7	35.9			ND	5,500
Upper Flood Channel	Post	23.1	5.7	8.0	41.6	26.1	48.9			ND	4,520
Old Alameda Creek	Post	20.7	3.7	7.9	NA	NA	41.0			ND	5,080

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7. Appendix
Appendix A

Table 1. Latitudes and longitudes of all sites monitored for the Invasive *Spartina* Project. The coordinates presented in this table were corrected to a common projection from the field forms.

Sites	Lat	Long
Coyote Point Marina Outer Harbor	37.58712999640	-122.31508000000
Coyote Point Marina Inner Harbor	37.58677876180	-122.31651296500
Fisherman's Park	37.58853068280	-122.33444713700
Near Sanchez Marsh	37.59214505230	-122.35530959200
San Mateo Creek	37.57507999640	-122.30572000000
Steinberger Slough	37.54003022310	-122.22913209100
North Steinberger Mouth	37.54743704590	-122.22525257500
Bair Island/B2 North Quadrant	37.53499999640	-122.20725000000
Oro Loma Marsh East	37.62434348800	-122.14940299800
Alameda Shoreline/Elsie Roemer	37.75017999650	-122.23776000000
Lower Flood Channel	37.56379976750	-122.13262831300
Upper Flood Channel	37.57173152150	-122.12068384700
Old Alameda Creek	37.59361804130	-122.10424631300

Appendix B

Monitoring Site Descriptions
Sites 2a, 2b, and 2d: Bair-Greco Island Complex
Bair Island/B2 North Quadrant. Located in the north of Outer Bair Island, this site covers about 65 acres of formerly diked area, next to Steinberger Slough. The targeted *Spartina* sites are in the lower marsh and along the slough.
Steinberger Slough. Covering the mudflats along the Bay and the northern end of Steinberger Slough, this sampling site is intensively colonized by invasive *Spartina alterniflora* hybrids. The area is surrounded by levees that border salt ponds further inland. About 80 acres of marshland are infested with a targeted five acres of *Spartina* at the sampling site.
North Steinberger Mouth. This area includes Belmont Slough, Belmont Island, North Point, Bird Island, and the northern part of Steinberger Slough along Redwood Shores. All sloughs and marshes of this 15-acre targeted area are bordered by levees.

Site 7a: Oro Loma Marsh East
The Oro Loma Marsh covers 364 acres of marsh habitat surrounded by levees. This restored salt pond has scattered *Spartina* infestations throughout the very soft mudflats. There are various industrial and commercial developments bordering the sampling area in the north and south. The Oro Loma Marsh is divided by a levee into the west and east

side of the marsh. The west side received imazapyr application by helicopter; the east side was sprayed with glyphosate using backpacks and trucks.

Site 17a: Alameda Shoreline/Elsie Roemer
The Alameda Island site includes several distinct areas within the stretch of southern Alameda Island, which runs from Ballena Bay in the west to the Bayfarm Island Bridge in the east. Within the estimated 17.3 acres of marsh at this site, there are some 12.5 acres of non-native *Spartina alterniflora* hybrids, including several large clones coalescing on the open mudflats south of the main infestation.

Site 13a: Old Alameda Creek
The Old Alameda Creek Channel North Bank sub-area consists of 33.6 acres of marshland along the channel comprising a 5-15 m wide bench grading from open mud and *S. foliosa* to pickleweed/ gumplant (*Grindelia stricta*) higher marsh up to the levee edge. This area runs from the mouth of the channel upstream approximately 4 miles to the “20-Tide Gates” flood control structure near Union City.

Site 1b and 1c: Upper and Lower Alameda Flood Control Channel
The Alameda County Flood Control Channel (ACFCC) is a large, unlined trapezoidal channel that runs from east to west through Hayward, Alameda County, draining a nearly 880 square mile watershed into the San Francisco Bay. The levees on both sides of the ACFCC are topped with multi-use public parks trails that are part of the San Francisco Bay Trail and Coyote Hills Regional Park. The flood control channel was sampled close to the Union City Boulevard Bridge and right at its mouth to the San Francisco Bay.

Site 19k, 19m, 19n, and 19o: West Bay Region (Near Sanchez Marsh, Fisherman’s Park, Coyote Point Marina Inner and Outer Harbor, San Mateo Creek)
The area encompassed by the West Bay Region includes all marshlands of San Mateo County extending south from the San Francisco/San Mateo County line in the north to the San Mateo-Hayward Bridge in the South. Excluding the Colma Creek Complex, there are 18 Sub-Areas in this area. Many of them are small marshes or mudflat areas bordered by light or heavy industrial development, rip-rap shoreline, Highway 101, the San Francisco International Airport, or other intensive uses. Several are partially restored marshes. Few of these Sub-Areas support diverse, intact native marsh conditions, and non-native *Spartina* has come to dominate each one of the Sub-Areas. Site 19n (Coyote Point Marina) comprises type I and type IV sites.

Appendix C

Field Data Report Forms