Final Report *June 2010*

Review/Synthesis of Historical Environmental Monitoring Data Collected at the San Francisco Deep Ocean Disposal Site (SF-DODS) in Support of EPA Regulatory Decision to Revise the Site's Management and Monitoring Plan

Prepared for:

US EPA Region 9
75 Hawthorne Street
San Francisco, CA 94105

Prepared by:

Germano & Associates, Inc.
12100 SE 46th Place
Bellevue, WA 98006

EPA ORDER No. EP069000274

Final Report

Review/Synthesis of Historical Environmental Monitoring Data Collected at the San Francisco Deep Ocean Disposal Site (SF-DODS) in Support of EPA Regulatory Decision to Revise the Site's Management and Monitoring Plan

Prepared for

US EPA Region 9
75 Hawthorne Street
San Francisco, CA 94105

EPA ORDER No. EP069000274

Prepared by

Joseph Germano
Peggy Myre
Lorraine Read
Drew Carey

Submitted by

Germano & Associates, Inc.
12100 SE 46th Place
Bellevue, WA 98006

June, 2010

TABLE OF CONTENTS

LIST OF FIGURES

Figure 19 Range (minimum to maximum) concentration of silver in samples collected from the SF-DODS and the reference area (columns). Baseline samples collected 1990-91. Green line showing maximum silver value reported from dredged material source areas through 2000 (0.6 ppm), for 2001-2003 (0.84 ppm), and from 2004 to present (1.4 ppm). The number of samples is shown in the center of the columns.

Figure 20 Location of the 21 stations used for pelagic fish monitoring surveys in the vicinity of the SF-DODS. D stations are disposal site stations; B stations are “buffer area” stations; and P stations are “peripheral area” stations.

Figure 21 Power Analysis Results from the SF-DODS benthic community data: relationship between the number of replicates per site vs. the Minimum Detectable Difference (MDD) as a percentage of the mean, given a type I error rate (alpha) = 0.05 and 80% power.

1.0 INTRODUCTION

The disposal of dredged material in ocean waters, including the territorial sea, is regulated under the Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA), 33 U.S.C. § 1401, ff. The MPRSA prohibits disposal activities that would unreasonably degrade or endanger human health or the marine environment. Under the Act, the U.S. Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers (USACE) have joint authority for regulating ocean disposal of dredged material and for managing ocean disposal sites. Permits for the transportation and disposal of dredged material into ocean waters are issued by the USACE (or, in the case of federal projects, authorized for disposal under MPRSA §103(e)) only after EPA concurs that environmental criteria and conditions established by EPA are applied. EPA designates Ocean Dredged Material Disposal Sites (ODMDS). Management of an ocean disposal site consists of (1) regulating the quantities, types of material, times, rates, and methods of disposing dredged material at an ocean disposal site; (2) developing and maintaining an effective monitoring program for the site; (3) recommending changes for site use, disposal amounts, or timing based on periodic evaluation of site monitoring results; and (4) enforcing permit conditions for approved dredging projects.

The San Francisco Deep Ocean Disposal Site (SF-DODS) was designated as the nation's deepest ODMDS in 1994 after a comprehensive 2-year ocean studies program and site designation environmental impact statement (EPA 1993). The SF-DODS is located approximately 80 kilometers (50 miles) off the coast in the Gulf of the Farallones region, in water depths ranging from 2,500 to 3,000 meters (8,200 to 9,840 feet) (Figure 1). Designation of the SF-DODS was effective on 8/11/1994. There is a Site Management and Monitoring Plan (SMMP) that details site use requirements (EPA 1998). Dredged material was first placed at the site in 1995.

The SF-DODS has two distinguishing characteristics that set it apart from other open-water dredged material disposal sites in the United States: 1). It is located off the continental shelf in water depths exceeding 3,000 meters; and, 2). The SMMP (EPA, 1994, revised in 1996 and 1998) is incorporated in the site's Final Rule [40 CFR 228.15 (1)(3)] (EPA 1999a).

1.1 Background

The EPA Final Rule initially designating the SF-DODS for dredged material disposal was published on August 11, 1994 (59 FR 41243). This initial rule established an "interim" allowable disposal volume of 6 million cubic yards per year. The maximum allowable disposal volume was reduced to 4.8 million cubic yards per year starting in January, 1997 (EPA Final Rule of December 30, 1996, 61 FR 68964). The reduction in allowable disposal volume was based on a revised prediction of long-term dredging needs conducted by the interagency Long Term Management Strategy (LTMS) for San Francisco Bay (LTMS 1996, 1998). The limit of 4.8 million cubic yards per year was subsequently made permanent in the EPA Final Rule published on July 23, 1999 (64 FR 39927). Through the 2007 disposal year, almost 16 million cubic yards of dredged material have been diverted to the SF-DODS from traditional in-Bay sites, reducing risks of disposal-related impacts within those sensitive waters, and, as described in this report, that reduction of risk has been accomplished without causing any significant impacts to the ocean.

Because of the unique setting of the SF-DODS (distance from shore and depth of water), there was a great deal of uncertainty (and because of that, initial controversy) during the site designation process about the behavior of dredged material during descent and its impacts after deposition on the seafloor. There is a wealth of information available about the environmental impacts of dredged material disposal in shallower coastal marine environments (Newell et al. 1998; Fredette and French 2004; also see http://el.erdc.usace.army.mil/dots/). However, before the designation of the SF-DODS, there was little available information on best management practices or long-term impacts of dredged material disposal in deep water (> 500 meters). In order to address all the concerns brought up during the site designation process and in response to comments on the final Environmental Impact Statement (EIS), both the USACE and EPA sponsored a series of multidisciplinary monitoring studies as part of the initial designation process and continued this diverse array of studies as part of the SMMP in the ensuing years after disposal operations started in 1995.

Even though the location of the SF-DODS was specifically selected to avoid important fishery areas and geographically unique or otherwise sensitive habitats, this disposal site has been the subject of the most intensive monitoring of any disposal site in Region 9, and it is one of the most actively and intensively monitored sites in the nation. To date, 15 years of monitoring data have been collected for the SF-DODS, and, on average, the field monitoring activities have cost approximately $1 million each year.

1.2 Statement of Need

While initially there were no data from sites in similar settings to support many of the predictions made in the site designation EIS (US EPA 1993), after 15 years of post-disposal operation monitoring, EPA is now in an excellent position to review all the results to date and consider the appropriate changes to the SMMP in the spirit of adaptive management. Several management actions affecting how the SF-DODS was used and monitored have been taken since the disposal site was initially designated by EPA in 1994. The practical lessons that were learned from the first project to use the site (the Port of Oakland 42-Foot Deepening Project) resulted in EPA clarifying many of the mandatory conditions contained in the 1994 rule. These clarifications were initially included in both instructions to the USACE in 1997 and then in the SMMP Implementation Manual (EPA 1998). In 1999, EPA published a final rule (Appendix A, 64 FR 39927) codifying these changes. These actions included:

- establishing a permanent annual disposal volume limit of 4.8 million yds^3 (reduced from 6.0 million yds^3);

- reducing the size of the surface disposal zone from a 1,000-m radius circle to 600-m radius, to better ensure that deposition of dredged material outside of the SF-DODS boundary would be minimized;

- reducing the maximum acceptable sea state for transportation of material to the SF-DODS from 18 feet to 16 feet;

- clarifying that disposal vessels may not be loaded to more than 80 percent of bin volume to minimize risk of spillage during transit through adjacent National Marine Sanctuaries;

- clarifying that each disposal vessel must be inspected prior to departure for the SF-DODS, and that a certification checklist must be completed and signed by the tug captain and the independent inspector for each trip;

- clarifying that disposal vessels may transit within the three mile exclusion zone around the Farallones Islands only when they are within the westbound vessel traffic lane established by the US Coast Guard;

- clarifying that the disposal vessel (scow) must have an acceptable navigation tracking system, and that the system must indicate the position of the opening and closing of the disposal vessel doors associated with disposal (tug's navigation system serves as secondary or backup);

- including a provision that, in addition to reporting to EPA and the USACE, the permittee must report any potential or actual violations of the SMMP (such as dredged material discharges) within the boundaries of a National Marine Sanctuary to the appropriate Sanctuary manager within 24 hours;

- clarifying the frequency of trips that include on-board independent observers (regarding potential seabird and marine mammal impacts) to a minimum of once per month and once every 25 disposal trips; and

- clarifying that complete dredging and disposal records must be submitted to EPA and the USACE at a minimum at the end of each project, annually for long-term projects, and at whatever other interval may be requested by EPA or the USACE.

In addition to these overall site management changes, EPA has modified some technical aspects of the annual monitoring program based on results obtained from previous years' monitoring. For example, additional benthic monitoring stations have been added over time to continue to successfully map the most distant margins of dredged material deposition around the disposal site. Also, the chemical analysis of off-site sediment samples as called for under Tier 2 in the SMMP has routinely been conducted, even though Tier 2 Chemical Monitoring was not triggered by the results of the Tier 1 studies.

The site designation Final Rule (40 CFR 228.15 paragraph (k)(vi)(3)(ix)) calls for the three tier site monitoring as well as periodic confirmatory monitoring concerning potential site contamination. The guidance for this site monitoring is described in the SMMP (EPA 1998). The periodic confirmatory monitoring is to be conducted at least once every three years to confirm that pre-disposal sampling and testing requirements are in fact adequately characterizing the potential toxicity of the sediments (EPA, 1994, 1998). To date, this confirmatory monitoring has been conducted once in 1997-1998.

The Final Rule states that once disposal operations begin at the site, the monitoring program should be implemented through December 31, 1998 (40 CFR 228.15 paragraph (k)(vi)(3)(x). After this time, the Regional Administrator may establish a minimum annual disposal volume (not to exceed 10% of the designated site capacity at any time) below which the monitoring program need not be fully implemented. EPA has invoked this provision to focus the monitoring on potential benthic impacts and suspend confirmatory monitoring.

Based on the wealth of information collected at this site over the past 17 years during the ocean studies program leading to the site EIS and continuing through the post-designation monitoring surveys, EPA is now in a position to fully address the concerns brought up during the EIS process as well as the uncertainties that existed initially about the behavior and impacts of dredged material disposal in offshore waters at these great depths. In the sections that follow, we will review and summarize the results to date of the physical, chemical, and biological studies performed in the water column and on the seafloor as well as the bird and mammal observations conducted since disposal operations began. At the end of the report we provide conclusions based on the review of the monitoring data collected through 2009.

PAGE INTENTIONALLY LEFT BLANK

2.0 REVIEW OF PAST MONITORING DATA

There exists a wealth of detailed information in the individual monitoring reports from each year's study, and interested readers are encouraged to examine any of the individual reports listed in the bibliography for details (SAIC 1991, 1992a, 1999a, 1999b, 2009; SAIC et al., 2003, 2004, 2005;.Tetra Tech 1999, 2000, 2001, 2002; ENSR 2005, 2006, 2007, 2008). The SF-DODS is located in an area of historical ocean disposal (SAIC 1991) and was established within Study Area 5, the environmentally preferred alternative for an ocean disposal site as identified in the site designation EIS (EPA 1993). This particular region of the ocean has been used historically as a chemical and conventional munitions disposal area; between 1951-1954, the general region also was used for disposal of low-level radioactive waste containers from defense-related, commercial, and laboratory activities (EPA 1993).

The site is located in a naturally dynamic, highly variable hydrodynamic region. This area of the ocean is seasonally influenced by three distinct water masses: warm (12-16°C) oceanic water, cooler newly-upwelled coastal water (8-10°C), and to a lesser extent lower salinity San Francisco Bay water. The convergence of these water masses results in frontal areas which vary with location and season in the vicinity of the disposal site. Typically, the warmer oceanic water dominates the area in the winter, while cooler upwelled water dominates in the late spring and early summer. However, changes in the dominant water mass at the disposal site itself are at times observed to occur even within a single day. Changes also occur on a longer time scale: for example, a major El Niño episode was in progress in 1998, followed by a La Niña episode in 1999. The area's oceanographic conditions are thus naturally quite variable on both short and long time frames.

The current site monitoring program for the SF-DODS as defined in the SMMP (EPA 1998) includes annual monitoring in three interdependent modules: Physical Monitoring, Chemical Monitoring, and Biological Monitoring. Each type of monitoring is "tiered" to ensure that adequate information for decision-making is collected in a cost-effective manner. For example, if adequate information is available in Tier I for a particular type of monitoring (i.e., physical, chemical, or biological), additional data collection in subsequent tiers is not required. In addition, the program calls for "periodic confirmatory monitoring" to address certain issues of public concern raised during the site designation process.

2.1 Dredged Material Disposal Operations

The site first received dredged material in 1993 as a result of a Section 103 ocean disposal permit granted to the US Navy for their dredging activities at the Alameda Naval Air Station and the Oakland Naval Supply Center Base. Approximately 1.2 million cubic yards (mcy) of dredged material was sent to what later became the SF-DODS site between May and December of 1993; in September, 1993, the Navy conducted a sediment profile imaging (SPI) survey at the disposal site at the midpoint of disposal operations to verify that the material was behaving as predicted by the modeling conducted in support of their Section 103 permit application (PRC 1995). This first post-disposal monitoring survey showed two important results:

1. Mapped location and thickness of the dredged material footprint matched reasonably well with the modeled dredged material dispersion predictions.

2. Impacts to the benthic community were less than anticipated; sediment profile images showed evidence that mixing and recolonization of the dredged material that was deposited on the seafloor had already begun..

After the Navy's one-time use of the area for their Section 103 permit, the site was officially designated two years later as an ocean disposal site by EPA. Since that time, the SF-DODS has received material from a variety of projects such as channel deepening in inner and outer Oakland Harbor, Richmond Harbor, and construction for the San Francisco Bay Bridge. Since the start of disposal activities in 1993, the site has received over 16 mcy of dredged material through 2009 (Table 1 and Figure 2). The volumes presented here are bin volumes, meaning volumes calculated by summing the estimated volume for each bargeload of material. Sums of individual projects from 1995-2009 are available in Appendix Table 3.

Table 1. Annual volumes of dredged material disposed at the SF-DODS

Estimated Bin Volume (cubic yards)		
Disposal Year	**Estimated Volume (cy bin)**	**Source**
1993	1,200,000	US Navy
1995	243,980	EPA 2002
1996	1,022,254	EPA 2002
1997	4,642,864	EPA 2002
1998	2,561,584	EPA 2002
1999	350,200	EPA 2002
2000	380,650	SI-ADISS[1]
2001	696,872	SI-ADISS[1]
2002	848,084	SI-ADISS[1]
2003	1,052,285	SI-ADISS[1]
2004[3]	446,000	SI-eTrac[2]
2005	149,600	SI-eTrac[2]
2006	1,078,302	SI-eTrac[2]
2007	1,425,900	SI-eTrac[2]
2008	78,336	SI-eTrac[2]
2009	58,740	SI-eTrac[2]
Total:	**16,235,651**	

[1] Silent Inspector (Automated Disposal Surveillance System) in combination with USACE Volume Tracking Database

[2] Silent Inspector (eTrac Engineering)

[3] Includes Bodega Bay

2.2 Monitoring Summary

The results of the monitoring activities conducted since 1991 will be presented and discussed in detail below (Sections 2.3-2.7). For orientation, we provide a brief review of the techniques and monitoring activities conducted at the SF-DODS (Table 2).

Physical Oceanography

Physical Oceanographic studies are conducted as part of site designation activities to validate and improve models used to predict dispersion of dredged material in the water column and deposition of dredged material on the seafloor at the SF-DODS. The initial studies were conducted prior to site designation as part of the US Navy project. These initial studies were vital in defining the expectation of dispersion and deposition at the site. Subsequent studies would be considered Tier 2 studies under Physical Monitoring (Table 2).

Table 2. Monitoring activities at the SF-DODS

Types and Tiers	Monitoring activity	Years
Physical		
Tier 1	Sediment Profile Imaging	1996-2010
Tier 2	Current measurements and modeling	1991-2*, 1997-8
Tier 3	Advanced ocean studies	None
Chemical		1990-1991*
Tier 1	Sediment sampling and footprint analysis	1996-2008
Tier 2	Chemistry analysis outside footprint and boundary	1997-2004‡
Tier 3	Tissue bioaccumulation	Reference area studies (1990-1995)
Biological		
Tier 1 Pelagic	Birds, Fish, Mammals	1996-2001
Tier 2 Benthic	Box core collection	1996-2008
Tier 2 Pelagic	Additional surveys	None
Tier 2 Benthic	Benthic community analysis	1996-2003
Tier 3 Pelagic	Advanced studies	None
Tier 3 Benthic	Advanced studies	None
Confirmatory		
	Bioassay and bioaccumulation	1998
	Caged mussel bioaccumulation	1997-8

* Baseline studies were conducted prior the site designation.
‡ Chemistry analysis has been conducted on Tier 2 samples although Tier 2 has not been triggered.

Physical Monitoring

The Physical Monitoring outlined in the site SMMP (EPA 1998) is conducted to determine the distribution of dredged material on the seafloor at the SF-DODS. Tier 1 monitoring is used to map the footprint of dredged material. If significant dredged material accumulation (>5 cm) is found outside the site boundary and Tier 1 chemical monitoring cannot establish that the material meets suitability guidelines for open water disposal of dredged material, Tier 2 physical monitoring might be conducted to improve the models used to predict dispersion in the water column and deposition on the sea floor.

In Tier 1, a sediment profile camera system (Rhoads and Germano 1982, 1986, 1990) is used to document the extent and thickness of the dredged material deposit both within the site boundaries and in the surrounding vicinity (Figure 3). Annual SPI surveys are conducted at selected locations within a standardized 1 nautical mile [nm] station grid (Figure 4). The objective for the SPI surveys is to define the spatial extent of the dredged material deposits.

Chemical Monitoring

Tier 1 Chemical Monitoring consists of collection, processing, and preservation of sediment samples from boxcores (Figure 5). These preserved sediments are used for chemical analysis in Tiers 1 and 2. In Tier 1, samples collected within the dredged material footprint are analyzed for common metals and organic contaminants. In Tier 2, samples collected outside the footprint and outside the disposal site boundaries are analyzed. In practical terms, this strict sampling and analysis protocol has been modified to provide comparative analysis of apparent, recent, or historical dredged material compared to ambient, so stations from outside the site have always been both sampled and analyzed (Figure 6; Section 2.5).

Biological Monitoring

Tier 1 Biological Monitoring has included monitoring of pelagic communities and benthic communities. Pelagic monitoring included regional surveys of seabirds, marine mammals and mid-water column fish populations. After the initial three year period following site designation, biological monitoring was focused on benthic assessments. Benthic monitoring consists of collecting and preserving box core samples in Tier 1 (Figure 5) and analysis of samples in Tier 2 (which is triggered if >5 cm of material is found outside the designated site boundaries). Tier 2 analysis includes a comparison of the benthic community within the dredged material footprint to benthic communities outside the footprint.

Confirmatory Monitoring

Confirmatory Monitoring consisted of sampling sediments from the dredged material footprint for 10 day bioassay and 28 day bioaccumulation testing and comparing the results to samples from outside the footprint and to pre-dredge testing results. Caged mussels were deployed in near-surface arrays around the disposal site for a year and the tissues analyzed for contaminants. An additional year of current meter data collection was also conducted, and computer modeling run using these new data, for comparison with the original oceanography data and dispersion modeling conducted for the site designation EIS. Confirmatory Monitoring has only been conducted once, based on the results and the relatively low volume of dredged material disposed at the site since 1998 (Section 2.7).

2.3 Review of Physical Oceanography Monitoring and Modeling

2.3.1 Oceanographic Monitoring

As part of the site feasibility studies prior to the initiation of disposal activities, current meters were deployed by SAIC and the Naval Postgraduate School (NPS) at six moorings between March 1991 and February 1992, and the data were used for model inputs (Abdelrhman 1992, SAIC 1992b, Tetra-Tech 1992, Hamilton and Ota 1993). The mooring locations were selected to provide broad regional data for disposal site selection. The initial modeling approach took current values from this set of data and projected the fall trajectories of surrogate particles from seven size classes. The model runs were used to generate predicted footprints of disposed material on the seafloor and to predict transport of particles relative to the boundaries of National Marine Sanctuaries. These model results were later compared with the dredged material map prepared from sediment profile images collected at the disposal site (Hamilton 2001 based on the data collected in SAIC 1996, 1999a, 1999b).

As part of the Third Year Confirmatory Monitoring, current meters and sediment traps were deployed at three moorings from November 1997 to November 1998 by the EPA and USGS after the disposal site had been designated and was in active use. These data as well as pre-designation data were used in a comparative modeling study (Hamilton, 2001, and formally written up in Noble et al. 2006). The 1997-8 mooring locations were selected to monitor the water column properties and the amount of suspended material found near the SF-DODS during actual disposal operations as well as to evaluate whether dredged material was transported into the Gulf of Farallones National Marine Sanctuary (Figure 7).

2.3.2 Physical Oceanography Results

Mean currents over the slope off the Farallon Islands tended to flow toward the northwest parallel to depth contours, but the mean flows were very weak. Within the water column the mean flows above 400 m depth near the disposal site were 2-8 cm/s. Near the seafloor, mean currents flowed down the submarine canyon toward the disposal site (the mooring was located up-slope, east, from the disposal site). Near bed currents were also weak with mean flows less than 4 cm/s.

Mean current speed and direction did not adequately describe the complexity of currents in the region around the disposal site. Tidal currents near the bottom flow in and out of the submarine canyon and were the dominant component of current fluctuations. Subtidal currents (fluctuations in current strength with periods longer than 33 hours) were dominant in the water column shallower than 1000 m. The subtidal current fluctuations could reverse the mean current flow over much of the upper water column. Subtidal currents tended to be highly correlated within the water column and across the region, averaging 15-20 cm/s. Although these subtidal currents were highly coupled within the water column, they were independent of the near-bottom subtidal currents.

Resuspension potential near the disposal site was estimated from both near bed current measurements and assumptions of boundary layer conditions (Noble et al. 2006). Bed shear stress calculations suggested that fine sand would not be resuspended during the measurement period but suggested that silt and clay might be resuspended into the 10 m thick boundary layer above the seabed. However, turbidity measurements in this boundary layer from transmissometers at two of the moorings (D2 and R1) did not correlate with measured current speed (and resultant bed shear stress). Current speed at the bottom was very low and consistent. It is difficult to validate the light attenuation measurements because the near bottom sediment traps at D2 and R1 were lost and the transmissometer failed at D1 (Figure 7) where near bottom sediment was collected. The observed near-bottom light attenuation had small peaks and increasing noise at mooring D2 from July to October 1998 during a period of low significant wave height. Noble et al. (2006) speculate that these peaks may have represented turbidity from higher disposal activity during the summer months. However, the disposal activity during these months was actually much lower than the preceding months (Figure 2) when there was very little measured light attenuation. The observed turbidity in the bottom boundary layer did not appear to be generated by either bed resuspension or dredged material disposal and must have come from events further away.

The most striking finding from the 1997-1998 data collection was the sediment trap results. Trap contents from the top traps at the two moorings along the barge transit route to the disposal site had unusually high concentrations of fine sand (the reference site trap ca. 20 miles away was empty). The bottom trap at the mooring near the disposal site collected large amounts of material with similar composition to the ambient bottom sediment. Trace metal analysis results suggested that sediments collected near the disposal site had enriched levels of Co, Cr, Mn, Pb, and V over another mooring and the EPA reference site (see Figure 7) values. The top traps near the disposal site had the highest concentrations of Co, Cd, and Pb; bottom trap sediments were collected in discrete time layers that showed considerable variation but generally lower values than the top trap. Trace metals and PAHs measured in mussels showed no evidence of uptake above reference except for Al, Mn, Se and Sn. Noble et al. (2006) concluded that the sand-sized material collected in sediment traps near the surface came from dredged material spilling from disposal barges transiting to the disposal site. They also concluded that the potential for resuspension of material at the disposal site was low, and any material resuspended from the bottom by currents would likely be transported primarily along the slope to the northwest, not upslope toward the sediment traps (Figure 7).

As a result of these sediment trap findings, EPA evaluated archived barge sensor data and discovered that many scows were indeed leaking sediments en route. Subsequent EPA scrutiny of the scows and compliance actions significantly reduced the amount of material lost during transit.

2.3.3 Modeling Results

The size and thickness of the dredged material footprint has been monitored on an annual basis since 1995. The majority of the dredged material volume has remained within the site's boundaries every year. Also, as predicted, a thin apron of material has spread out beyond the site's margin over a 14 year period (Figure 8).

The models developed for predicting disposal at SF DODS were particle-tracking algorithms (Hamilton 2001). These model results give a statistical representation of the deposition of particles on the bottom. This is achieved by dividing the dredged material into size classes with distinct sinking rates, and each size class is tracked by a small number of surrogate particles released at hourly intervals at the disposal site. The modeled results for SF DODS were calculated from the predicted movement of particles. Particle movement was calculated from a combination of sinking rates and horizontal transport based on the current meter results from the 1991-1992 study, using the volume disposed in 1996 (calculated as 2.952 mcy for the 'disposal year' 1996-1997 at the time of the study; see Table 1 for calendar year data); this was then compared to similar modeling results using the 1997-1998 current meter data. The particle results were converted to a deposition depth on a modeled seafloor based on bathymetry. The comparison with actual disposal footprints measured from the 1997-1998 season was reasonable and provided confidence in the modeled predictions (Figure 9).

2.3.4 Discussion of Physical Oceanography and Modeling Results

The model used for predicting the fate of disposed material at the SF-DODS was a conservative approach developed because of limitations in existing disposal models for deep water. Models of disposal assume that the material leaving the barge behaves as a cloud of particles and water (effectively a dense liquid) that sinks under the influence of gravity during a convective descent phase. This continues until the cloud either impacts the bottom or entrains sufficient water to reach neutral buoyancy (collapse phase; Johnson 1990). These models do not deal explicitly with the material's fate after it reaches the collapse phase. In deep water, disposed sediments reach neutral buoyancy well before they reach the bottom (at roughly 1000 m depending on water content) and begin to spread horizontally and fall as individual particles.

The SAIC model begins with a mean monthly particle load at the surface and tracks individual particles. This will likely overestimate the dispersion of particles because it does not account for the convective descent phase of disposal. The actual disposal activity at the SF-DODS is not composed of mean monthly particle loads, but consists of discrete disposal events interacting with the particular water column characteristics for each event. The particle tracking algorithms assume individual particles are released over a period of time (in this scenario, coarse silt particles take 25 days to reach the seafloor in 3000 m of water). This most closely approximates the “cloud” of loose material released in the water column during disposal but does not account for the coherent mass of material that falls rapidly through the water column before entrainment of water slows descent and disperses the mass. The movement of water masses near the surface is most likely to affect the “cloud”, and the movement of water masses deeper in the water column will affect the transport of the dispersed mass of individual particles. This conservative approach has been able to establish that even in the worst case scenarios; disposal activities will contribute very few particles to the seafloor within the nearby marine sanctuary. However, this model approach will not provide sufficient precision to model footprints accurately enough to guide subsequent monitoring activities, and therefore should not be used for this purpose. Deposition footprints within the disposal site could be modeled more effectively with a two phase model. However, current meter records are limited in the vicinity of the disposal site; accurate prediction of particle fate and transport would need to be conducted with accurate data on current conditions existing close to the site during the disposal activities. This level of data collection and subsequent modeling is not warranted, because disposal footprints can be verified and monitored much more cost-effectively with actual seafloor observations (as required by the SMMP).

Current meter records from the 1997-1998 deployments were expected to provide more clarity about El Nino conditions. Both 1991-1992 and 1997-1998 are considered be strong El Nino years (http://ggweather.com/enso/years.htm). The results from that set of current data (with different spatial and vertical coverage) seemed to indicate that in these years; relatively strong poleward flow on the Farallones slope may differ from the classical description of Hickey (1979). It remains unclear if La Nina or “average” years produce distinctly different current patterns over time. However, actual seafloor observations of deposition patterns indicate that the existing data do reasonably predict deposition.

2.3.5 Conclusions from Past Physical Oceanographic and Modeling Studies

Current meter records and particle tracking models have predicted that dredged material released at the SF-DODS will contribute very little material to the water column or the seafloor within the Gulf of the Farallones National Marine Sanctuary. Results suggested that less than 2 mg/L of fine silt class material will reach the Sanctuary boundaries less than 1% of the time during active disposal.

The current records and modeling support the conclusions in the EIS that material deposited at the disposal site is not likely to be resuspended or transported by the relatively weak near-bottom currents. If recently deposited sediments or bioturbated surface layers were transported, they are likely to be transported along the slope to the northwest (Noble et al. 2006).

Modeling of footprints on the seafloor corresponded reasonably well with the actual deposition footprints detected with sediment profile imaging (SPI) for the years with current meter data available. The model does not account for slumping or consolidation of deposits, and SPI results may not always distinguish deposits from more than one year of disposal. However, the results are sufficiently close to provide confidence that the seafloor monitoring results and model estimates are comparable; therefore, the overall conclusions reached in the EIS (EPA 1993) about the appropriateness of the physical setting of the site based on the modeling runs were appropriate and applicable (Figure 9).

2.4 Review of Physical Data

Physical monitoring is designed to confirm (map) the dredged material footprint on the bottom (Tier 1), and to help determine whether additional oceanographic studies are needed to improve the models used to predict dispersion in the water column and deposition on the sea floor (Tiers 2 and 3). In Tier 1, a sediment profile camera system (Rhoads and Germano 1982, 1986, 1990) is used to document the extent and thickness of the dredged material deposit both within the site boundaries and in the surrounding vicinity. The SPI images allow analysts to distinguish locations with dredged material layers (Figure 10) from the ambient seafloor (Figure 11) as well as reworking of dredged material by recolonizing benthic animals (Figure 12). This mapping focuses on whether dredged material is remaining within the site boundaries as predicted, i.e., whether there is a significant accumulation of dredged material outside the site boundary. The SMMP defines a "significant dredged material accumulation" as five centimeters (5 cm) per year. If less than 5 cm of dredged material accumulates outside the site boundaries in any one year, then higher-tier physical monitoring will generally not be required. If greater than 5 cm accumulates outside the disposal site in any one year, then either higher-tier physical monitoring will be initiated, or appropriate management actions will be taken.

2.4.1 Mapping the Dredged Material Footprint

The physical monitoring aspect of the current SMMP involves annual SPI surveys at selected locations within the 1 nautical mile [nm] spaced station grid (Figure 4). SPI observations were always taken at the 11 stations within the perimeter until 1997, after which not every interior station was sampled every year. The objective for the SPI surveys was to define the spatial extent and provide a footprint map of the dredged material deposits. Consequently, some of the stations within the SF-DODS boundary were dropped over time in exchange for more stations outside the previously-sampled grid. In subsequent years, additional stations were added, particularly to the north and west, in order to track the thin deposits of dredged material accumulating outside the site boundary.

Generally, the majority of the dredged material has remained within site boundaries. However, the apron of the deposit (thin layers that spread laterally from the main deposition) has been expanding annually to encompass the footprint area (cumulative deposits > 5cm all years, Figure 8). A number of known mis-dumps were identified between 1995 and 2000 (EPA 2002) that resulted in some dredged material being placed outside the site boundary. These mis-dumps and equipment failure on the scows prompted modifications to the ocean disposal requirements discussed in Section 1.2, including the scow certification checklist (incorporated on all subsequent disposal operations after completion of the Port of Oakland -42 ft. deepening project in 1997). Fewer mis-dumps occurred after 2000 (EPA, pers. comm.).

Although the cumulative area outside the site where dredged material has at any given time exceeded 5 cm (Figure 8) is almost equal in area to the designated site (26.5 km^2), there have been no adverse impacts detected in the benthic community outside or inside the site boundary even when thin layers accumulate outside the boundary (see below).

During the October 2000 monitoring survey, a substantial layer (> 14 cm) of distinctive material was detected at Station 16 outside the site boundary (TetraTech, 2001). This material was composed of fine sand overlying gray clay, and the monitoring report noted that the gray clay may have been the previous years' material (Station 16 had an average of 4.8 cm of material in the 1999 survey). However, the sand layer alone was 6 cm thick, exceeding the 5 cm definition of "significant" dredged material accumulation outside the site perimeter year in a single year.

It was uncertain at the time whether the deposit seen at Station 16 was in fact dredged material. The resolution of the basic sampling grid was not fine enough to conclusively determine that this deposit was part of a "tongue" or "outgrowth" of material extending from the disposal site as opposed to being an isolated area of mounding. In addition, the sediment chemistry results for Station 16 appeared to be most similar to off-site stations where little or no dredged material was present (EPA 2002). The apparently rapid accumulation of material at station 16 since the previous survey was particularly surprising given that only 660,980 yds^3 of material had been discharged at the SF-DODS since the 1999 survey. In contrast, a maximum average of only 4.8 cm had been identified there in past years following as much as 3.6 million yds^3 of disposal. Station 16 is approximately 100 meters shallower than (up slope from) the SF-DODS boundary, and over 200 meters shallower than the center of the disposal site (Figure 8). Substantial quantities of dredged material from properly disposed loads would not be expected to disperse and settle in this location unless highly unusual oceanographic conditions were present. Disposal records (based on automatically-collected scow tracking data) indicated that there had been no known mis-dumps in the immediate vicinity of Station 16, either during 2000 or in previous years (EPA 2002).

Station 16, however, is at the foot of one of the steeper slopes in the vicinity of the SF-DODS. Active slumping has been identified in the general area in the past (EPA 1993). It was therefore possible that the relatively thick deposit detected at Station 16 after the 2000 monitoring event was related to slumping of native material from up-slope, rather than a result of dredged material disposal. Higher-intensity sampling around Station 16 was therefore included in the 2001 survey to help identify whether the material was indeed dredged material from the site or slumped native material from up-slope. A series of 4 stations separated by 0.5 nautical mile was collected in a line radiating SE from the disposal site (Stations 16NW, 16, 16 SE and 39; TetraTech 2002). Analysis of these photographs showed that while a distinctive layer of dredged material from recent disposal activity was not present, there was historical dredged material at all four stations, ranging in thickness from 4.1 cm in the southeast end to 4.7 cm at the northwest end of the transect closest to the disposal site. While the thick layer of dredged material detected at Station 16 in the 2000 survey was not present in the 2001 survey, it did appear that the sediment in the vicinity of this location was dredged material and not turbidites from slumping of up-slope native sediment (TetraTech 2002).

Mapping the physical extent of the dredged material footprint has continued each year; while the material continues to spread along a NW-SE axis as predicted from modeling runs (see previous section), the results to date show that the apparent accumulated thickness of dredged material outside the site boundary is still less than 10 cm (Figure 8). Because the sediment is reaching the bottom as a rain of individual particles at these substantial water depths, the freshly deposited particles are constantly being reworked into the underlying sediments by infaunal burrowing and feeding activity. It has become increasingly difficult over time to distinguish between historical dredged material deposits and deposits resulting from the past year’s disposal activities within the site boundary. However, the distinct optical and textural characteristics of dredged material still allow scientists to discriminate between native sediment and the deposited material so that the overall spatial extent of the material can be accurately tracked over time.

2.4.2 Review of Historical SPI Survey Results

Data from SPI surveys over the ten-year period between 1996 and 2006 were used to evaluate the relationships between benthic community response and the presence, thickness, and volume of dredged material disposed. For this purpose, historical SPI survey data were compiled and reviewed for consistency; an initial inspection of the data identified several stations from the October 1997 survey with curious results (thick layers of dredged material reported along with large values for mean apparent RPD depth). The apparent RPD (Redox Potential Discontinuity) depth is a visual (color change) measure of the relative activity levels of burrowing deposit feeders. A deeper RPD is associated with higher levels of activity and less disturbed conditions. A shallower RPD is associated with lower levels of activity and recently disturbed conditions (such as dredged material disposal).

An inspection of the corresponding sediment profile images for these reported results indicated substantial errors in image interpretation and the need for a broader quality assurance (QA) check of the historically-reported results. Every image from the January 1996, December 1996, and October 1997 surveys was reviewed by a qualified senior scientist (J. Germano), and the reported SPI results for apparent RPD, successional stage, and dredged material thickness were verified and corrected where necessary. The results of this 100% QA check of these early SPI surveys showed the following:

- **January 1996**: 34 images reviewed from 28 stations.
    - Mean apparent RPD was underestimated in only two replicate images by approximately 50%. The corrected and remaining originally-reported RPD values for site ranged from 0 to 3.6 cm.
    - Dredged material thickness was generally underestimated by as much as 500%; the presence of dredged material was incorrectly indicated in six replicates (five replicates missed the presence of dredged material, and one image had dredged material reported that was not present).
    - Successional stage was underestimated in five replicates (originally reported as Stages 1 or 2 when Stage 3 taxa were present).

- **December 1996**: 40 images reviewed from 28 stations.
    - Mean apparent RPD was underestimated in six replicate images by as much as 70%. Both corrected and remaining originally-reported RPD values ranged from 1.3 to 5.9 cm.
    - Dredged material thickness measurements showed observation error with no directional bias; overestimation error (up to 220%) was much greater than underestimation error (70%). Presence/absence of dredged material was accurate in all but one replicate image.
    - Successional stage was correctly interpreted.

- **October 1997**: 48 images reviewed from 30 stations.
    - Mean apparent RPD depth was overestimated in 11 replicate images by as much as an order of magnitude. Corrected RPD values ranged from 0.5 – 4.7 cm (originally-reported RPD values ranged from 1.5 – 15cm).
    - Dredged material thickness was underestimated in 25 replicate images by as much as 600%. Presence/absence of dredged material was accurate in all replicates analyzed.

- Successional stage interpretation was underestimated in 18 replicate images (all were originally designated Stage 1, but should have been reported as Stage 1 on 3, Stage 2-3, or Stage 3).

Based on this review, it appeared that the utility of the historical SPI surveys would be limited due to inaccurate interpretation of some of the earlier images. Consequently, further QA checks were performed on images with reported characteristics that either had been shown to have a tendency to be misinterpreted or were just simply questionable. We identified 119 additional images with high RPD values (>4.5 cm) and Stage 1, or high RPD values and with reported dredged material thicknesses greater than 2 cm. Of these, a random selection of approximately half these images was made. This resulted in an additional 65 images selected (10% of the 621 images) from the December 2000 to September 2004 surveys for a QA check with the following results:

- Mean apparent RPD was overestimated in every replicate chosen by as much as 75%. Corrected RPD values ranged from 1.1 – 5.1 cm (originally reported RPDs ranged from 1.9 – 7.5 cm).
- Dredged material thickness was accurately reported in 81% of the images. In the remaining 12 images (19%), even the accurate interpretation of the presence or absence of dredged material was a problem. In all but one image, dredged material presence was missed in the original results, but the results subjected to QA review indicated thicknesses varied from 1.8 – 9.4 cm. In one replicate, dredged material thickness was reported as 3.4 cm but should have been recorded as being absent.
- Successional stage interpretation was underestimated in every replicate image. Typically, the successional stage was reported as only Stage 1, but a QA review indicated that these should have been reported as Stage 1 on 3, Stage 2-3, or Stage 3.

In all, the QA review included 100% of the images from the three earliest surveys, and 10% of the images from the 2000 to 2004 surveys. Based on this QA review the following conclusions were reached regarding the utility of the historical SPI survey results for quantitative analysis:

- **Mean apparent RPD.** With the exception of the October 1997 survey, the RPD results appear to have been originally reported without consistent bias and with limited errors. The original data, replaced with results for the QA'd images, should be acceptable for quantitative analysis.

- **Dredged material thickness.** The measurement of dredged material thickness appears to have been inaccurately estimated in some of the historical surveys. However, the most suspicious dredged material values were selected for QA, so the corrected data set could be cautiously used for quantitative analysis. The presence/absence of dredged material showed better accuracy (90% accuracy overall) and should be suitable for inclusion in further correlation analyses.

- **Successional Stage.** The successional stage results appear to have been frequently and consistently underestimated. We believe the reported data cannot reliably be used in a quantitative analysis. The images that were reviewed, however, indicated that Stage 3 animals had been present at nearly every station, including stations within the site that had an accumulation of recent dredged material; in recent surveys, evidence of Stage 3 taxa continue to be found within the site (Figure 12). At least qualitatively, the results of the QA check can be used as evidence of benthic recolonization throughout the site, even in the presence of dredged material.

Utilizing the available results from past monitoring surveys, including the corrected historical SPI data (mean apparent RPD and presence/absence of dredged material), historical annual disposal volumes (Table 1), and the benthic summary data (Table 4-2, ENSR 2005), we investigated several relationships between dredged material volume, presence, and benthic effects.

2.4.2.1 Evaluation of Benthic Impairment

The mean apparent RPD data from the corrected historical SPI survey dataset were evaluated to allow for comparisons among subsets of the data, including stations with or without dredged material, and in years with large or small disposal volumes. The mean apparent RPD is a proxy for benthic impairment, a shallow RPD would indicate some recent disturbance or impairment of the benthic community.

The distribution of the RPD data were summarized using the overall cumulative distribution function (CDF) and conditional CDFs (CCDF). The CCDFs are just CDFs for subsets of the data ("conditional" on particular features of the dataset, such as dredged material present; Figure 13). Information about the distribution is obtained from a CDF or CCDF curve by reading the y-value (probability) associated with the x-value (RPD). At each point on a curve, the y-value indicates what percent of the samples in that dataset have RPD values less than or equal to the associated x-value. Curves that are further to the right have a higher median RPD value for the distribution (i.e., generally better conditions), and steeper curves indicate distributions with less variability. The data shown in Figure 13 are summarized in Table 3.

Table 3. Number of Stations by Presence/Absence of Dredged Material and Annual Disposal Volume

Annual Disposal Volume (yds^3)	Dredged Material Absent	Dredged Material Present	Totals
<100,000[1]	8	60	68
>250,000[2]	124	159	283
Totals	132	219	351

[1] Includes October 1999 and December 2000 surveys, only.

[2] Includes surveys from 1996-1997, 1999, 2001-2004, and 2006.

Using an RPD value of 1 cm or less to indicate the presence of a benthic impairment, the data sets have the following features:

- 5% of all stations (18/351) have mean apparent RPD values ≤ 1 cm.
- 8% (18/219) of the stations with dredged material present have mean apparent RPD values ≤1 cm.
- None of the 132 stations with dredged material absent have mean apparent RPD values ≤ 1 cm.
- 24% (16/68) of the stations from small volume disposal years (<100K yds^3) have mean apparent RPD values ≤ 1 cm.
- <1% (2/283) of the stations from large volume disposal years (>250K yds^3) have mean apparent RPD values ≤ 1 cm.
- Mean apparent RPD values tend to be higher when dredged material is absent (Figure 13: CCDFs where dredged material is absent are found to the right of the respective CCDFS where dredged material is present); and RPD values are lower among the small volume disposal years.

There is a higher incidence of biological effects (i.e., RPDs ≤ 1 cm) at stations where dredged material is present (8% vs. 0% where dredged material is absent), but there is an insufficient number of stations (only 18 out of 351) to suggest a widespread problem. Surprisingly, relatively low annual disposal volumes do not suggest that the benthic conditions are better (i.e., higher RPDs); in fact, the data suggest the opposite (Figure 13: CCDFs for small volume stations have the lowest medians). If there are any effects of disposal volumes on the incidence of lower RPDs, they cannot be separated from temporal effects. While annual changes in recruitment could increase or decrease the size of the potential community available to colonize newly deposited sediment, the most likely explanation for the variation found in mean apparent RPD values is related to the time interval between the monitoring cruise and the last disposal event. Given the thin layers of material that are settling to the bottom, the majority of the recolonization on the dredged material is from existing fauna either burrowing up through the newly-deposited layer to re-establish themselves at the new sediment-water interface or lateral migration from the ambient seafloor into the newly available habitat space.

The relationship between mean apparent RPD values and dredged material thickness is illustrated in Figure 14. The range of mean apparent RPD values consistently decreases as the depth of the dredged material increases. However, even at stations with dredged material thickness as great as 13.5 cm, the mean apparent RPD values still exceed 1 cm, an indication of biological reworking activity. Station 13, at the center of the disposal site, has consistently had dredged material thicknesses of 12 cm or greater while mean apparent RPD values improved from 0 cm in January 1996 to 1.9 cm in December 1996, and then fluctuated between 0.8 cm and 2.1 cm.

The community metrics derived from the benthic grab results (discussed below in Section 2.6.3) were plotted against annual disposal volumes and station specific dredged material depth from the corrected historical SPI surveys (Figures 15-16). Clearly, these community metrics (i.e., Total Abundance per $0.1m^2$, Valid Species count, Pielou's J, and Fisher's log-α) do not show a relationship between disposal volumes nor dredged material thickness. The ranges for abundance and valid species richness are quite variable across the range of dredged material disposal and accumulation. These results suggest that either a) spatial variability of the benthic activity is inherently greater than the effect of disposal volumes or depth of accumulated dredged material, i.e., the disposed dredged material has had no impact on the benthos; or b) these metrics do not adequately represent biological impacts, or c) both.

2.4.3 Conclusions

In summary, the both the SPI and benthic community results indicate that while there are areas within and outside the disposal site boundaries where the benthic communities have been affected by dredged material disposal, these conditions do not consistently persist over time, nor are they strongly associated with dredged material thickness, dredged material presence, or disposal activity:

- Very few RPD values are within the range of depressed biological activity (<1cm).
- RPD values show a reduced range with increasing dredged material thickness, but there are images indicating active biological reworking activity (RPD values > 1 cm) on dredged material thicknesses as great as 13.5 cm.
- Successional stage (in the corrected dataset) was predominantly 3 (or 1 on 3). There are images showing Stage 3 animals even at the center of the disposal site (Station 13) on dredged material thicknesses that exceeded the camera penetration (Figure 12). Evidence of mature successional assemblages continued to be documented at all stations monitored between 2007-2009.

- There are no apparent relationships among benthic community metrics and annual disposal volumes or dredged material thickness.
- Overall there is no evidence of major physical changes that suggest widespread or long-term impairment of the benthic community as a result of disposal operations.

2.5 Review of Chemical Data

The current SMMP Implementation Manual (EPA 1998) includes chemical monitoring of disposed dredged material. Sediment samples have been collected from the area within and surrounding the SF-DODS and analyzed for sediment chemistry each year since monitoring began. A summary of the ranges of measured chemical values for each monitoring year is provided in Appendix Table 1. Ranges were calculated for the stations reported with no dredged material present (“Ambient”) and for those with measurable dredged material (“Footprint”), using ½ of the detection limit for values reported below detection. Note that if a station had measurable dredged material during one survey, it was classified as part of the footprint for all follow-on years, assuming historical dredged material was still present at the station. Chemical values measured in both Ambient and Footprint stations then were rolled up for all years, as presented in Table 4.

Chemical measurements results generally have been compared to values measured in pre-dredge test sediments (Appendix Table 2); no specific numeric criteria or statistical tests have been used, just a simple comparison of maximum values between the two data sets. This approach has been sufficient to date because, with minor exceptions, all of the chemical concentrations measured have been lower than maximum values reported from the pre-dredge testing data. In many cases, the values are within the ranges measured both during the baseline surveys, conducted in 1990-91 (SAIC 1991), and at the SF-DODS reference area (EPA 1999; Table 4). This section presents a summary of the sampling design and sediment chemistry results at the SF-DODS from 1996-2008, with implications for modification of the chemical monitoring tier in the revised SMMP.

2.5.1 Sediment Characteristics of the SF-DODS and the Reference Area

Both the SF-DODS and the SF-DODS reference area are located on the continental slope outside of the mouth of San Francisco Bay (Figure 1). The SF-DODS was sited close to the foot of the slope in an area characterized by slow deposition and by very little mass movement of sediment. Mass movement of sediment has been largely restricted to the steeper slopes that border submarine canyons and gullies (Chin and Ota 2001). The reference area identified by EPA for the SF-DODS is located in approximately 1,285 meters of water, and is located approximately 35 kilometers from the SF-DODS (Figure 1). The reference area is located in shallower water on a plateau on the continental slope, and is characterized by slow deposition and little documented sediment movement (Karl 2001). Long-term sedimentation rates in the vicinity of the reference site have been reported at an average of 0.11 cm/decade over the last 10,000 years (Gardner et al. 1997).

The SF-DODS reference area is not sampled during the annual monitoring surveys of the SF-DODS. During the process of dredged material projects, physical, chemical, and biological testing data are collected and evaluated relative to reference as described in the Ocean Testing Manual (EPA/USACE 1991). Sediment physical and chemical data have been collected at the reference site both by the EPA (EPA 1999) and by the USGS (Bothner et al. 1998; Chin and Ota 2001). The EPA has developed a reference area database for comparison to dredged material projects, due to the expensive and logistically difficult task of sampling at the reference area. The database includes several sets of sediment test data including sediment chemistry, bioassay, and tissue bioaccumulation data (EPA 1999).

Table 4. Summary of range of sediment chemistry measured at SF-DODS and the reference area.

Chemical	**SF-DODS Baseline (1990-91)**	**SF-DODS Ambient[1] (1996-2008)**			**SF-DODS Footprint[2] (1996-2008)**			**SF-DODS Reference**
	Range	**N**	**Range[3]**	**Avg ± 1SD**	**N**	**Range[3]**	**Avg ± 1SD**	**Range[3]**
Conventionals								
Total Solids (%)	-	28	28 - 37.1	32 ± 2	140	17.3 - 65.2	40.3 ± 7.6	33 - 59[4]
Percent Fines	78 - 99	16	69.85 - 98.3	90.63 ± 8.6	105	29.3 - 98.4	70.1 ± 14.8	40 - 84
TOC (%)	2.7 - 3.9	28	2.06 - 3.23	2.8 ± 0.3	140	0.5 - 5.6	2 ± 0.7	0.63 - 1.5
Metals (mg/kg dw)								
Arsenic	nd - 5.2	27	2.9 - 5.4	3.7 ± 0.7	140	0.7 - 8.3	3.6 ± 1.3	2.2 - 5.3
Cadmium	nd - 0.38	27	0.1 - 0.528	0.3 ± 0.1	140	0.09 - 0.53	0.24 ± 0.09	0.3 - 0.6
Chromium	91 - 167	27	40.2 - 90	71.3 ± 13	140	31.1 - 120	59 ± 16	69 - 283
Copper	20 - 62	27	28.3 - 64.2	44.1 ± 9.4	140	7.3 - 62	33 ± 10	18 - 86
Lead	nd - 12	27	5.16 - 25	10.06 ± 5.7	140	3.5 - 35	10 ± 6.8	5.1 - 26
Mercury	0.13 - 0.24	27	0.02 - 0.158	0.1 ± 0.04	140	0.02 - 0.26	0.095 ± 0.05	0.1 - 0.2
Nickel	77 - 115	27	54.1 - 85.6	67.9 ± 7.8	140	4.8 - 97	59 ± 12	51 - 238
Selenium	nd - 6.6	27	1.8 - 4.6	3.4 ± 0.8	138	0.14 - 5	2.2 ± 1.2	0.6 - 2.6
Silver	nd - 0.64	27	0.2 - 1.2	0.5 ± 0.19	140	0.015 - 2.4	0.48 ± 0.34	0.2 - 1
Zinc	91 - 147	27	67.3 - 113	87.7 ± 13	140	36.3 - 135	74.2 ± 18	61 - 288
Organics (ug/kg dw)								
TPH	-	9	10 - 35	22 ± 8	65	9 - 65	24 ± 11	nd - 17
LPAHs	nd	24	8.865 - 144	57 ± 52	126	5.5 - 1298	64 ± 120	nd - 77
HPAHs	nd - 220	24	20.295 - 192	90.638 ± 65	126	14 - 2749	151 ± 270	nd - 115
PAHs	-	24	30.015 - 336	147.832 ± 115	126	20 - 4047	215 ± 382	nd - 192
Aldrin	-	27	0.39 - 2.8	0.87 ± 0.67	140	0.09 - 3.6	0.87 ± 0.64	nd
Dieldrin	nd	27	0.13 - 2	0.77 ± 0.42	140	0.08 - 2.4	0.87 ± 0.55	nd
Total BHCs	-	27	0.74 - 22.25	3.98 ± 4.4	138	0.4 - 16.6	3.4 ± 2.7	nd
Total DDTs	nd	27	1.445 - 23.75	4.729 ± 4.2	138	1.04 - 15.3	4.23 ± 2.3	nd - 2.1
Total PCBs	nd	27	9.45 - 120.5	56 ± 38	138	5.6 - 143.5	58 ± 37	1.9 - 3.9[4]
Tri-n-butyltin	-	19	0.255 - 1.8	1.2 ± 0.6	96	0.163 - 38	1.6 ± 3.8	nd - 1.3

nd: not detected All calculations made using 1/2 of the reported detection limit for values below detection.

[1] Calculated over stations with no measurable dredged material in any survey (see text for further information).

[2] Calculated over stations with measurable dredged material (see text for further information).

[3] Minimum - maximum reported range; data below detection are reported as 1/2 of the detection limit.

[4] Values from Bothner et al. 1998 as only values available.

2.5.2 Current SMMP Chemical Monitoring Protocols

Chemical monitoring addresses the effects of dredged material deposition on the chemical and physical characteristics of bottom sediments within and adjacent to the SF-DODS. The overarching goal of routine chemical measurements is evaluation of the long-term potential for contaminant accumulation in sediment and potential exposure of benthic and demersal organisms to toxic and/or biologically-available contaminants. A secondary benefit of the chemical monitoring module of the SMMP is to confirm that only approved material is being disposed at the SF-DODS.

Pre-disposal testing is conducted to ensure that sediments approved for disposal at the SF-DODS are not toxic and also do not pose a significant risk of adverse effects due to bioaccumulation of contaminants. Therefore, the current SMMP assumes that, if the sediment was approved for disposal at the SF-DODS, the ranges of chemistry values associated with the approved suitable dredged sediments are applicable metrics to compare against samples collected at the disposal site itself. No specific statistical tests or method of summarizing the testing data have been recommended; in the bulk of monitoring reports, this analysis consists of a simple comparison of maximum values between the SF-DODS samples and from the pre-dredge test data.

Currently, chemical monitoring in Tier 1 consists of collecting and analyzing sediment samples from within the perimeter of the SF-DODS. The SMMP also requires collection of samples from outside the site boundaries for archival and potential chemical or biological analyses in subsequent tiers; in almost all cases these samples have been analyzed and results reported even when higher tier monitoring has not been triggered. The sampling design has changed over the years; the footprint of dredged material near or outside the perimeter of the site has been the most recent focus for sediment chemistry sampling (see next section). The SMMP notes that if on-site sediment chemistry is “significantly” elevated relative to that which was pre-approved for disposal, further chemical monitoring at higher tiers will be required.

In the current SMMP, if significant elevations of chemicals within the site boundary are detected, then Tier 2 monitoring is triggered, and the sediments collected from outside the disposal site boundary are analyzed and compared in the same way as Tier 1. The implication of this tier is that on-site chemical contamination is of less concern if it has not spread outside of the boundaries; if the results of the off-site samples do not show elevated values, then higher-tier chemical monitoring is not required. To date, samples from both inside and outside of the SF-DODS have been sampled and analyzed simultaneously. Tier 3 monitoring, if needed, includes chemical analysis of tissues from fish and/or infaunal organisms collected from the site and its surroundings; based on these results, the need for management actions is then evaluated.

2.5.2.1 SF-DODS Surveys and Sample Design

Chemistry samples were collected from this area in 1990-91 prior to the implementation of the monitoring program as part of the baseline monitoring for the US Navy Section 103 disposal permit (SAIC 1991). These baseline samples represented background conditions at the SF-DODS; baseline conditions were different from the background conditions at the SF-DODS reference area, because material had been historically disposed at the SF-DODS location (Chin and Ota 2001). Post-disposal monitoring samples have been collected every year from 1996 to the present (Table 1). In most of the reviewed reports, the data have been compared to samples collected from dredging projects conducted since the prior monitoring survey, primarily from Richmond and Oakland Harbors. In more recent monitoring years, the data have been compared to cumulative data ranges (minimum-maximum) for pre-dredge testing data, because as more sediment has been disposed at the SF-DODS, the ability to link sediment samples to specific dredging projects has become increasingly problematic (Appendix Table 2).

In the most recent years of the reviewed monitoring data, stations were classified as located within the apparent, recent, or historical dredged material footprint, or in ambient sediments with no apparent dredged material present. Sediment samples have been obtained during the annual monitoring surveys using a partitioned boxcore sampler (Figure 5) at stations usually sampled in conjunction with the sediment profile imaging (SPI) system. The ability to identify dredged material as “recent” or “historical” was based on the analysis of sediment profile images. Ambient sediments, taken from locations showing no dredged material (based on SPI results), are expected to have similar physical and chemical attributes as the baseline data collected prior to the start of dredged material disposal operations. Sediment samples from each survey are analyzed for grain size, TOC, trace metals, chlorinated pesticides, polychlorinated biphenyls (PCBs), polynuclear aromatic hydrocarbons (PAHs), and organotins. Laboratory methods and quality control requirements are consistent with pre-disposal sediment testing requirements (EPA/USACE 1991).

A review of the sample design through the years of chemical monitoring demonstrates that the objective of sampling has changed over time primarily due to the lack of measured chemical concentrations elevated above source material. The stations selected for sediment sampling have varied from year to year, although there has been some consistency for a few long-term stations. Stations have been classified as being outside or inside the site (Figure 4); beginning in 2000, samples were collected along the perimeter and outside of the site, rather than from the bulk of the dredged material deposit, acknowledging that exposure to sediment inside the site is short-term (until the next dredging episode). More recent surveys classified stations as being within the apparent, recent, or historical dredged material footprint, or in ambient sediments with no apparent dredged material present.

Many stations have been sampled repeatedly through the years of monitoring (Figure 6). The stations with the longest history of sampling of the dredged material footprint include 10, 13, 17, 19, and 23; additional station locations have been added as the dredged material footprint has expanded. The location of the sampled stations is critical in that the SMMP has specific tiers tied to whether the station is located within the perimeter of the disposal site boundary or outside of the site (EPA 1998). The variability of the sample design over the last decade of monitoring is an indication of the changing emphasis of chemical monitoring objectives.

In the first two years of monitoring (1997-98), the majority of stations sampled were located on or inside the disposal site boundary (Table 5). For the next six years through 2004, less than half of the stations sampled were located on or inside the site boundary. In the period between 2002 and 2007, the same four stations were sampled inside the site: Station 13 (at the center), and Stations 17, 19, and 23 (on the perimeter; see Figure 6). In 2008, only two stations (13 and 19) were sampled and analyzed.

Table 5. Ratios of inside versus outside sampling stations to the SF-DODS site boundary

Survey Year	**Number of Stations**		**Ratio (%) Inside/Total**
	Inside + Perimeter	Outside	
1997	11	6	65%
1998	9	3	75%
1999	6	7	46%
2000	2	10	17%
2001	2	7	22%
2002	4	11	27%
2003	4	12	25%
2004	4	12	25%
2005	10	2	83%
2006	9	3	75%
2007	9	3	75%
2008	2	0	100%

The modification of the sampling design appears to reflect a change of focus from the SMMP's Tier 1 (inside) to Tier 2 (outside) of the SF-DODS boundary. Until monitoring in 2005, the sample locations were placed farther from the site center to target the widening spread of the dredged material apron. Detection of contaminants of concern in surface sediments within the boundary has not only been rare, but is of less concern, because the sediment within the boundary, by definition, is ephemeral; new surfaces are constantly being created as new dredged material is deposited in subsequent years. In the last four years of chemical sampling (2005-2008), the lack of detection of chemicals of concern outside the site has yet again focused the sampling effort within or at the perimeter of the site (Table 5).

In summary, after the first 3 years of monitoring, the change in the sediment sample locations from preferentially inside to dominantly outside of the SF-DODS perimeter for the next 5 years had changed the focus of the monitoring from confirmation ("Is unacceptable sediment winding up at the site because of poor criteria for pre-dredge testing?") to assurance that no degraded sediment located outside of the site was causing unacceptable biological effects. Boxcore samples have consisted of a composite of the top 10 cm of sediment, regardless of the actual thickness of the dredged material present; this is representative of the average mixing depth for infauna (Boudreau 1998) and an appropriate sample of the biological exposure zone if one were concerned about contaminant uptake in the benthos. Confirmatory monitoring, if necessary, should use samples that consist exclusively of dredged material for the most accurate comparison, but the body of data collected within the SF-DODS site demonstrates no evidence that pre-dredge testing protocols are insufficiently protective. Rarely have any contaminants been measured that were higher than the maximum measured in the pre-dredging samples; a few exceptions are discussed in the next section.

2.5.3 Summary of Chemical Monitoring of the SF-DODS

Monitoring results are summarized below for samples collected from stations with measurable dredged material (as determined by SPI data) within the footprint of dredged material, and for samples collected from stations with no dredged material (ambient). The data are compared to baseline data (1990-91; SAIC 1991), as well as the SF-DODS reference area (Table 4). In addition, the data are also compared to reported ranges of chemical concentrations measured from the range of reported pre-dredge testing data (Appendix Table 2). The reported ranges and material sources are summarized from reported concentrations in the monitoring reports. All chemical results are reported in dry weight units.

2.5.3.1 Physical Parameters

Both the SF-DODS and the reference area are on the continental slope in areas that are atypically sandy relative to other continental slopes (Karl 2001). The sand source is probably relict sediment from the San Joaquin-Sacramento River system that has been transported and winnowed from the mouth of the San Francisco Bay estuary (Dean and Gardner 2001). The mean grain size decreases with increasing depth on the slope, from dominance by silty and clayey sands in Pioneer Canyon (near the SF-DODS reference area), to primarily silt and clay closer to the disposal site itself (Karl 2001). Cores collected from the reference and surrounding area by the USGS (Bothner et al. 1998) resulted in grain size content similar to those recorded in the SF-DODS Reference Area Database (EPA 1999), ranging from 40-84% fine-grained sediment (silt and clay; Table 4).

Sediment at the SF-DODS collected prior to the monitoring program during baseline surveys was dominated by silt and clay, with a total fines content ranging from 78-99% (SAIC 1991). This range was similar as measured in the first two monitoring surveys in January and December of 1996, but the sand portion of samples collected at the SF-DODS has increased following the period of large volume disposal in 1997-98 (Figure 17). This results in a lower fine-grained fraction within the dredged material footprint (70.7 ± 15%) as compared to ambient samples (90.6 ± 8.6; Table 4).

The highest total organic carbon (TOC) concentration reported during the SF-DODS monitoring was 5.6% at station 116 in 2003 (SAIC et al. 2004), categorized as within the dredged material footprint with small, but measurable dredged material (0.55 cm). Other than that outlier value, the range of measured TOC within the footprint ranges from 0.5 to 3.5%, which is less than the range between the source material and baseline measurements (Figure 18). The reported range of TOC measured in Richmond and Oakland Harbors over the entire monitoring period (1994-2004; SAIC et al. 2005) is quite narrow (0.08-1.7%, Appendix Table 2), which is typical of TOC in San Francisco Bay sediments (SFEI 2007). Reported TOC in cores collected from just the upper 1 cm of sediment at the reference site was similarly low (1.2-1.9%; Bothner et al. 1998). However, ambient stations around SF-DODS were higher, ranging from 2.1-3.2% TOC; and TOC in the baseline studies around SF-DODS was also high at 2.7-3.9%. The higher concentrations of TOC at the SF-DODS compared to reference and to Bay dredged material, has implications towards potentially reducing the availability of contaminants, although the active diagenetic processes at these water depths and temperatures are quite different than those found in the source harbor locations (Bothner et al. 1998).

2.5.3.2 Chemical Parameters

Sediment chemistry values measured at the SF-DODS from 1996-2008 have, in almost all cases, been well below those measured in the source pre-dredge test sediments, and therefore have not triggered Tier 2 sampling and analyses (Appendix Table 2). There have been reported detections of silver (Ag) and selenium (Se) higher than concentrations reported in pre-dredge test data; these cases are discussed in more detail below. These elevated concentrations have been in samples collected within or near the disposal site boundary and were therefore detected more often in the earlier monitoring studies when sampling was focused within the disposal site.

2.5.3.2.1 Metals

The incidence of measured metal concentrations reported at levels higher than in the associated source material has been rare in SF-DODS monitoring. Silver was noted as being higher than concentrations reported in pre-dredge test samples in some of the surveys (Figure 19), with highest reported concentrations in 1996-97 (average for footprint 1.0 mg/kg, Appendix Table 1). The highest detection of Ag (2.4 mg/kg) was at the center station in December 1996 (EPA 2002), and therefore most likely associated with the large volume of material disposed in that year (Table 1).

The apparently elevated concentrations of Ag reported from the disposal site monitoring are due primarily to the relatively low concentrations measured in the source material. Compared to ambient and to the reference areas, the concentrations are not particularly elevated except for the high value in December 1996 (Table 4; Figure 19 combines reference and footprint, see Appendix Table A-1 for details). The maximum Ag concentration reported from the sediment characterization data for the in-Bay dredging years 1997-2000 (EPA 2002) was 0.6 mg/kg (dry weight), lower than the maximum measured at the reference site (1.0 mg/kg), the baseline samples (0.64 mg/kg), and in the SF-DODS ambient sediment collected during the 2003-04 surveys (0.62 mg/kg, Appendix Table 1). The highest reported Ag value from dredged material characterization data following this period was 0.84 mg/kg from Oakland Harbor, and in the 2004 monitoring year, a value of 1.4 mg/kg was reported for Oakland Harbor (SAIC et al. 2005). Since 2002, the maximum Ag value has remained below this 1.4 mg/kg threshold (Figure 19). It appears from these data that the high value in December 1996 has not reoccurred in any areas sampled within or outside the footprint of dredged material.

Selenium (Se) was the only other metal measured at concentrations greater than that of reported source ranges (Table 4). The highest Se concentration reported in pre-dredge test samples was 2.0 mg/kg (SAIC et al. 2005). The maximum Se concentration measured at the SF-DODS was higher than 2.0 mg/kg in almost all surveys conducted at the SF-DODS; but this includes baseline and ambient monitoring samples as well as sediments from the SF-DODS reference area (2.6 mg/kg). The highest reported Se value was 6.6 mg/kg, measured during the baseline survey (SAIC 1991). This suggests a potential persistent background source of Se, rather than uncharacterized dredged material being the source of any elevated Se concentrations measured at the site. For comparison, the maximum reported Se value measured in San Francisco Bay was 1.7 mg/kg (SFEI 2007).

2.5.3.2.2 Organics

The maximum concentration of polynuclear aromatic hydrocarbons (PAHs) measured during monitoring of SF-DODS sediment was 1,298 μg/kg for total low molecular weight (LMW) PAH, and 2,749 μg/kg for high molecular weight (HMW) PAH (Table 4). These values are higher than LMW and HMW PAHs (maximum of 144 and 220 μg/kg, respectively, Table 4) measured in baseline and ambient samples as well as in reference sediment (maximum of 77 μg/kg and 115 μg/kg, respectively; Table 4), but far lower than the maximum measured in the source areas for dredged material. The reported maximum LMW and HMW PAH concentrations for samples deemed suitable for SF-DODS disposal are 13,993 μg/kg and 36,985 μg/kg for samples from the Port of San Francisco (Appendix Table 2). Since the measured concentrations of PAHs in post-disposal monitoring have remained well below the maximum concentrations approved for disposal at SF-DODS, further sampling or analysis for an upper level tier have not been triggered.

In more recent surveys, low levels of detected pesticides were below those reported in the tested sediments, so that no further analyses were triggered. As an example, the maximum concentration of alpha-BHC measured in SF-DODS samples (12 μg/kg) was in 2002 (SAIC et al. 2003). By comparison, the highest reported value of alpha BHC over the dredging years 1994-2004 was 25 μg/kg (SAIC et al. 2005).

Total DDT (sum of detected concentrations for DDT and its degradation products DDD and DDE) occasionally has been measured at above detectable levels in SF-DODS samples over the years (maximum of 24 μg/kg in an *ambient* station in 2004; Appendix Table 1); however, these concentrations are an order of magnitude less than the maximum measured in the source sediments (e.g., 280 μg/kg from Richmond Inner Harbor, SAIC et al. 2005; Appendix Table 2). Continued confirmatory monitoring for bioaccumulative chemicals of concern (BCOC) will further the confidence that the testing program is effective at continuing to ensure that no bioaccumulative chemicals are present at unacceptable levels at SF-DODS.

2.5.4 Chemical Monitoring Conclusions

Measured chemical concentrations in the sediment have generally not exceeded those background values found either at the site prior to disposal or at the SF-DODS reference area; the few chemical compounds whose concentrations have exceeded background values have still been well below any value to cause any potential concern for biological effects.

2.6 Review of Biological Data

The biological monitoring module of the current SMMP addresses the potential effects of dredged material disposal on two marine ecosystem components: pelagic (seabirds, marine mammals, and fish) and benthic/demersal (bottom-dwelling invertebrate communities). Potential impacts to marine birds, mammals, and fish were expected to be localized (limited to the immediate vicinity of the disposal site) and to occur within a limited time frame during and immediately after actual disposal operations. Physical impacts to the benthic community were expected to last somewhat longer and to be readily detectable within the footprint area of dredged material accumulation (EPA 1993).

2.6.1 Pelagic Seabird and Marine Mammal Monitoring

Many species of marine birds and mammals are far-ranging in seasonal migration patterns in and out of the Gulf of the Farallones region and/or over large areas within this region. Consequently, there are inherent difficulties in directly linking any potential effects from localized dredged material disposal in the relatively small area of the SF-DODS to changes in regional populations without regard to other important factors. These other factors can include regional climate variations, natural variations in regional ocean circulation patterns, stochastic variations of biological populations, and human-induced effects such as adverse impacts of fishing gear, point and non-point sources of pollution, and marine debris. The SMMP therefore calls for any effects of dredged material plumes on marine bird and mammal populations to be evaluated with a regional time series approach, using available long-term regional databases, such as those containing Point Reyes Bird Observatory's (PRBO) 10+ years of annual breeding season census data; other long-term regional databases may be utilized as well.

2.6.1.1 Bird and Mammal Data

Regional population censuses, with concurrent collection of oceanographic data, have been conducted along transects through the disposal site as well as through adjacent areas for comparison. Census data collected during these monitoring efforts have been statistically compared to the disposal site and off-site areas, as well as to the historic (PRBO) database. Additional observations on a smaller spatial scale have been conducted regularly [1] by trained observers riding on disposal tugs traveling to and from

---

[1] Observations from disposal tugs initially were required at a minimum frequency of one trip per month during any period when dredged material disposal is occurring. In the July, 1999 revised Final Rule and SMMP, EPA increased the frequency so that observers must also be present at least once every 25 disposal trips. This ensures that an increased frequency of

the SF-DODS. The focus of these observations was to assess any detectable real-time disposal event impacts to marine birds and mammals using monitoring protocols already established (PRBO) to assess these populations. Observers kept detailed logs of all observations pertaining to marine birds and mammals prior to, during, and following an observed disposal event.

Regional surveys and periodic observations of seabirds and marine mammals were conducted by H.T. Harvey & Associates annually from 1996 through 2001. The annual reports submitted to the Corps San Francisco District (H.T. Harvey and Assoc, 1997, 1998, 1999, 2000, 2001, 2002) covered monitoring during the periods from November 1 through October 31 of each study year (1995/1996 – 2000/2001). The regional surveys were conducted during daylight hours concurrent with the three NMFS cruises (for fisheries and limited oceanographic monitoring) that were timed each year to correspond with the major oceanographic regimes or "seasons" in this region: the "Winter" or Davidson Current season (Nov.-Feb.), the "Upwelling" season (March-June); and the "Oceanic" season (July-Oct.). The seabird and marine mammal surveys were conducted while the NMFS vessel was in transit between ocean sampling stations. Periodic observations were also conducted from tugs that towed disposal scows from San Francisco Bay to and from the SF-DODS. These observations were conducted more frequently in years of higher disposal (32 and 28 observational trips in 1997 and 1998, and 3-7 trips in 1999-2001), and nearly year-round. Dredged material was discharged during both daytime and nighttime trips.

2.6.1.2 Bird and Mammal Results

Beginning with the 1997 monitoring report, H.T. Harvey began presenting analyses of both "large-scale" (waters within a 40 nautical mile [72 km] radius of the SF-DODS) and "small-scale" (waters within 8 nautical mile [15 km] of the SF-DODS) data from seabird and marine mammal observations. Evaluations included statistical comparisons among years of the post-designation period data (1996 onward), as well as between the post-designation and pre-designation periods (1985-1994) for the same area. As more data became available over time, evaluations included comparisons among the three oceanographic seasons and between periods of greater or lesser disposal activity. Following the last survey in 2001, analyses were also conducted to evaluate whether distribution and abundance patterns changed with distance from the SF-DODS <u>within</u> the small-scale (<8 nm radius) area.

The results from all these surveys can be summarized by the following:

- During the observational trips, it was generally found that seabirds did not feed on the scows. Exceptions were noted in the years when the scows carried material

---

observation takes place during periods of high disposal activity, as was experienced during the Port of Richmond deepening project.

from maintenance dredging projects (maintenance dredging projects remove a relatively thin layer of material from the bottom, including the biologically active surface sediments where infaunal invertebrates are found). In contrast, the other projects considered to be “new work” construction tend to be dominated by deeper sediments which are likely to contain a much lower density of infaunal organisms. No marine mammals were seen associated with scows in transit or during materials release during any of the cruises.

- Survey results from all years prior to 2001 showed little indication that disposal of dredged material at the SF-DODS was affecting the distribution or feeding behavior of seabirds, either regionally or at the “small scale” in the vicinity of the disposal site. Regional abundance data showed that variations in observations of seabirds were related to large-scale, warm-water events, unrelated to disposal of dredged materials at the SF-DODS.
- Analyses following survey year 2001 indicated that seabird abundance increased with increasing distance from the SF-DODS up to 3 nm (5.5 km) of the disposal site center. It was also found that seabird abundance was statistically higher during periods of no disposal activity, with the strongest effect confined to the immediate vicinity (within 1 nm, or 1.8 km) of the disposal site. Note, however, that the SF-DODS dimensions are approximately 7.5 km north to south and 4 km east to west. Therefore the apparent effects on seabird abundance and distribution identified in the 2001 report are largely confined to the area within the disposal site boundaries.
- Region-wide, marine mammal abundances were reported to have shown annual declines from 1996 to 2000, but increased somewhat in 2001. This pattern was consistent at both the small and large scales, and among all predominant marine mammal species, and is thought to reflect a long-term decline in oceanic productivity in the overall California Current system. There was no relationship between marine mammal density and distance from the SF-DODS, nor between mammal density and disposal activities, indicating that variation in marine mammal densities were not related to disposal site activities at the SF-DODS.

2.6.1.3 Bird and Mammal Discussion

Scows carrying dredged material with higher densities of infaunal organisms provided feeding opportunities for seabirds; however, the frequency of this happening was rare throughout the monitoring period (1996-2001). When the dredged material did attract seabirds, the risk of exposure to contaminants through the infaunal organisms was low because of the chemical and biological testing required for the sediments destined for open ocean disposal. Even if occasional feeding did occur on the scows carrying disposal material, it would not have introduced any risk to seabird populations.

Seabird densities were lower at the disposal site during periods of high disposal activity. The mean density of birds within 8 nm of the SF-DODS only varied by 2 birds per km^2 between the periods of active and non-active disposal. It is possible that birds may be avoiding the site because of noise, or because of decreased water clarity which would limit feeding opportunities for piscivores and planktivores. Within one nautical mile of the disposal site center, the species having the highest densities during non-disposal periods were generalists, including large gulls, Northern Fulmars, and albatrosses, followed by piscivores and planktivores. Lower abundances of piscivores and planktivores during periods of disposal activity could be explained by disturbance from disposal vessel traffic, or lower water clarity which limits visibility when diving or for seeing food items near the surface when on the wing. The abundance of piscivores was three times higher at 1-3 nm than they were at 0-1 nm during periods of disposal activity. This could be explained by a re-distribution of the birds which had been feeding at the disposal site center but moved to the closest waters that were not affected by disposal activity.

Linear regression analyses of the log-transformed seabird and marine mammal densities were used to evaluate the importance of environmental variables, distance from the disposal site, and disposal site activities. Statistically significant regression coefficients ($p<0.05$) were used to infer importance of independent variables. The data used in the regression analyses were density observations from continuous 15-minute intervals. The sample sizes were very high (typically ranging from ca. 300 to 3000) which led to statistically significant results even with very low R^2 values. The seabird results for the 2001 survey reported statistically significant models with R^2 values ranging from 13% to 27% of the variance explained. While the statistical significance of these results may be valid, their ecological significance may not be particularly strong because of the small differences detected as a result of the large sample sizes.

2.6.1.4 Bird and Mammal Conclusions

The extensive monitoring data collected between 1996 and 2001 generally indicated that the densities of seabirds and marine mammals were not adversely affected by activities at the SF-DODS. Density observations within the small scale vicinity of the SF-DODS (within 8 nm) generally followed the same patterns as those observed on the large scale (within 40 nm). The apparent effects of disposal activities within the “inner” area of the SF-DODS (from 1 to 3 nm) were viewed as a short-term impact of limited magnitude.

2.6.2 Pelagic Fish Monitoring

Similar to marine birds and mammals, many species of pelagic fish are far-ranging in seasonal migration patterns and/or occur over large areas within the Gulf of the Farallones region. Consequently, there are similar difficulties in directly linking any potential effects of dredged material disposal at the SF-DODS to changes in regional populations, without regard to other factors such as those listed previously for marine birds and mammals. Any effects of dredged material disposal on selected pelagic fish species were evaluated in part based on data from annual Juvenile Rockfish surveys conducted by the National Marine Fisheries Service (NMFS). The rationale for targeting larval and juvenile fish is their greater sensitivity relative to adult fish. The trawl surveys occupy transects within the disposal site as well as in adjacent areas for comparison. Catch statistics between transects were compared and evaluated in the context of the historical NMFS database.

2.6.2.1 Pelagic Fish Data

Regional cruises were timed each year to correspond with the major oceanographic regimes or "seasons" (Winter, Upwelling, and Oceanic) in this region (Table 6). The National Marine Fisheries Service, Tiburon Laboratory (NMFS) conducted four seasonal surveys from September 1996 to September 1997 (Roberts et al. 1998); subsequent surveys from 1998 – 2001 were conducted by San Francisco State University (McGowan et al. 2001, 2003). During each cruise, trawl samples were made at an array of 21 stations: four stations in the disposal site, ten "buffer area" stations, and seven "peripheral area" stations (Figure 20). During some cruises, not all stations were sampled, and in some cases, two additional shoreward stations were sampled when time permitted.

Table 6. Timing of trawl samples with monthly disposal volumes at the SF-DODS.

Survey Date	**Monthly Disposal Volume (yds^3)**	**Season**
Sept. 1996	121,056	Oceanic
Feb/March 1997	647,125	Winter
June 1997	359,514	Upwelling
Sept. 1997	523,863	Oceanic
March 1998	606,416	Upwelling
May 1998	355,485	Upwelling
Sept. 1998	0	Oceanic
Feb. 1999	0	Winter
May 1999	0	Upwelling
Sept. 1999	0	Oceanic
Feb. 2000	2,959	Winter
May 2000	94,055	Upwelling
Sept. 2000	0	Oceanic
Feb 2001	0	Winter
May 2001	0	Oceanic
Sept. 2001	103,326	Winter

Biological collections were made from the upper 200 meters of the water column by bongo nets (for small planktonic organisms, focusing on small larval fish and invertebrates), Tucker trawl (also for planktonic organisms, but especially for larger fishes and euphausiids), and, midwater trawl gear (for larger taxa in the June 1997 cruise, primarily pelagic juvenile rockfish).

A suite of ancillary oceanographic information was collected on each cruise, including near-surface temperature and salinity (continuous measurement with a hull-mounted thermosalinometer); current speed and direction (continuous measurement with an Acoustic Doppler Current Profiler [ADCP]); and temperature, conductivity, ambient light, and chlorophyll concentration to a depth of 500 meters (measurement at each sampling station with a Conductivity-Temperature-Depth [CTD] instrument equipped with a fluorometer). Chlorophyll was also measured directly from water samples taken at the surface, the chlorophyll maximum depth (which varied by location, as identified by the fluorometer data), and the 1% light level depth. In addition, water samples were collected from eight depths (surface to 500 meters) at each station for nutrient chemistry (nitrate and silicate).

Statistical analysis of catch data was done using analysis of variance (ANOVA) on individual fish and planktonic species (only those present in at least 75% of the stations) to test for differences in abundance among the three areas (disposal, buffer, and peripheral). McGowan et al. (2001) also conducted a Discriminant Function Analysis (DFA) on the community abundance data for fish and plankton to compare community patterns among the three areas.

2.6.2.2 Pelagic Fish Results

The oceanographic data collected during the cruises once again suggested that regional oceanographic conditions exerted a predominant influence on the distribution, abundance, and condition of zooplankton and juvenile fish in the Gulf of the Farallones region. This was expected, because the SF-DODS is located in a dynamic hydrographic region that experiences both distinct “seasons” and longer-term influences such as El Niño and La Niña conditions.

The vertical profile of light-transmissivity layers in the study area may have indicated detection of dredged material in the water column. In February of 2000 (140,800 yds^3 disposal in January; 3000 yds^3 disposal in February) there were two low transmissivity depth strata observed through the study area, although none were observed in February 2001 (no disposal in January or February 2001). Similar patterns were observed during the May and September sampling: the year with disposal volumes detected depth strata with low light transmissivity, while the year with no disposal had none. Low light transmissivity levels were not associated with reduced chlorophyll concentrations (indicating a decrease in water column productivity). The duration or effect of this reduced light transmissivity on fish distribution and abundance could not be detected with the study design.

Analysis and comparison of the catch statistics revealed few statistically significant differences between the disposal site and locations outside the site. Often, species abundances appeared to be higher inside the disposal site than outside it. When disposal activity at the SF-DODS was high during August 1998, rockfish, total fish, euphausiids, and cephalopods all were more abundant inside the disposal site in the September 1998 survey (although these differences were not statistically significant).

Overall, there was no coherent pattern in the data to indicate any adverse effect of disposal at the SF-DODS on abundance of juvenile fish or plankton. Abundances varied by area, season and gear; with no consistent results suggesting lower abundance within the disposal area. McGowan (2001) used DFA to compare the community data among the three areas. The DFA resulted in correct classification of disposal stations by the community characteristics, indicating that disposal stations tend to be similar amongst themselves. The results did not indicate, however, how many buffer or peripheral stations were classified into the same group as the disposal stations, so it is not clear if the disposal area stations were distinctly different. The result showing the similarity of disposal area stations may have been an artifact of the study design, which had the four disposal stations clustered close together while the other stations were spread over a much wider spatial scale (Figure 20). This community analysis was not repeated in the 2003 report.

The availability of monitoring data from 1999 allowed some time-series evaluation to be performed for Euphausiids. The winter cruise data on spatial distribution and relative abundance of this important krill species was compared among the sampling areas (disposal site, buffer, and peripheral) and among the four years (1996 through 1999). The species was less abundant at the disposal site stations compared to buffer or peripheral stations in 1996 and 1997. However, it was more abundant at the disposal site compared to the buffer and peripheral areas in 1998 and 1999. Also, there seemed to be no correlation between krill abundance and amount of dredged material disposed at the SF-DODS in January and February (before the winter sampling cruises). From 1996 through 1998, the amount of January-February disposal increased each year at the SF-DODS, and krill abundance also increased. But in 1999, when there was no disposal at all at the SF-DODS in January or February, the pattern was reversed and krill was at its highest abundance of any of the four years.

Sublethal effects, as indicated by physiological condition of juvenile rockfish, indicated no adverse impacts attributable to the SF-DODS. The fish appeared to be growing faster (1997) and were heavier (weight to length ratio, 1998) within the disposal site than outside it. In 1999, the condition analysis for myctophid fish showed mean dry weight to be slightly lower in the disposal site than outside it, but the difference was not statistically significant. For the 2000 – 2001 surveys, on only one cruise (May 2001) did the relative weight of myctophids differ among station groups, and the weight was heavier at the Disposal site than the Buffer or Peripheral stations.

2.6.2.3 Pelagic Fish Discussion

Results of the physical/chemical profile indicated that the area was dynamic and highly variable, both vertically and horizontally, although these conditions were well-described with the water column profile data obtained. The survey design, which composited taxonomic results over 200 meters of the water column, was not sensitive to the influence of changing oceanographic conditions over the vertical profile sampled. McGowan (2003) concluded that the survey design used was an oversimplification of the problem, because it did not account for the scale and pattern of oceanographic influences on the distribution and abundance of organisms. A better design would have been one that focused on the three general areas (disposal, buffer, and peripheral) and also within specific depth strata. However, the highly dynamic nature of the waters within the vicinity of the SF-DODS suggests that any water column effect of dredged material disposal on pelagic fish abundance would be obscured or overridden by the ocean currents in this area.

Even with these caveats, the average abundance of pelagic fishes within the top 200m of the water column did not show a consistent pattern across the disposal, buffer, and peripheral areas. Some species were higher at the disposal site in one cruise and then lower in another; similarly, there were no apparent differences in mean abundance among any of the areas. The statistical power of the ANOVAs used to detect differences among areas for individual species abundances may have been rather low for some of the individual species (low statistical power means that statistically significant differences will not be found unless the differences are very large). However, the patterns in the data presented (McGowan 2001, 2003) did not suggest a problem with reduced populations at the disposal site.

2.6.2.4 Pelagic Fish Conclusions

The mean oceanographic conditions as well as the seasonal and inter-annual variability were well described by the vertical and horizontal water column profiles taken during the 1996 – 2001 surveys. In addition to the oceanographic and biotic information obtained during these surveys being useful for coastal resources management, the distribution, abundance, and physiological condition of krill, fish larvae, and juvenile fishes does not appear to be negatively affected by any of the dredged material disposal activities at the SF-DODS.

2.6.3 Benthic Community Monitoring

The assumptions behind the benthic monitoring component of the SMMP's biological module are somewhat different than for the pelagic environment. Adverse impacts to the benthic infauna within the boundary of the disposal site are expected as a result of disposal operations (EPA 1993). The major effect within the disposal site is expected to be physical (mortality due to burial by deposited sediments, habitat modification due to changes in sediment grain-size and texture, etc.). In addition, natural variation in benthic population structure is expected over time both within and outside the disposal site. Therefore, the need for detailed benthic community evaluation is only indicated if significant accumulation (defined in the original SMMP as more than 5 cm) of dredged material occurs outside the disposal site. Benthic infauna are still collected from boxcores each time chemistry samples are taken inside and outside the disposal footprint during the annual sediment sampling and preserved for archival storage in the event that future analyses are required. However, unless the yearly physical accumulation of dredged material outside the disposal site boundary exceeds the 5 cm trigger level, benthic community samples are not analyzed but archived instead.

2.6.3.1 Benthic Community Data

ENSR (2005) analyzed 120 archived benthic infaunal samples collected between January 1996 - September 2003 and reviewed results. Samples were collected from a predetermined grid (Figure 4). Starting in 1999, the emphasis of the benthic infaunal sampling shifted from an assessment of the immediate impacts of disposal within the site boundary to an understanding of the impacts of dredged material deposition outside of the site boundary. A summary of the benthic locations sampled over the years of monitoring is shown in Table 7. A single box core sample was collected at each sediment sampling location, and the top 10 cm from 10 sub-cores (collectively equivalent to a surface area of 0.1 m^2) was processed for infaunal analysis. Organisms were sieved using a 300 µm-mesh sieve, with specimens identified to the lowest possible taxonomic category (usually species).

The calculation of benthic summary statistics included the number of valid species[2] and total density (individuals per 0.1 m^2, includes indeterminate organisms of valid species). Several diversity indices were also calculated, including Shannon's H' (base 2), Pielou's evenness value J', Fisher's *alpha* (Clarke and Gorley 2001), and rarefaction (ESn) curves (Sanders 1968 as modified by Hurlbert 1971). Multivariate analyses (cluster analysis and PCA-H) were performed on the community data to evaluate and describe patterns in the community structure among stations and over time.

---

[2] valid species excludes juveniles and indeterminate specimens that could not be identified to species level, epifauna, shell-borers, and parasites (ENSR 2005, p. 12)

Table 7. Benthic box core samples collected as part of the SF-DODS monitoring surveys (Table 3-1 from ENSR 2005).

Station	Jan 1996	Dec 1996	Oct/Nov 1997	Oct 1998	Oct 1999	Oct 2000	Oct 2001	Sep 2002	Sep 2003	Total
1		1	1							2
2		1	1	1						3
3	1	1	1							3
6					1	1	1	1	1	5
7	1	1	1	1	1					5
8	1	1	1	1						4
9	1	1	1							3
10		1	1		1	1	1	1	1	7
11	1	1	1		1					4
12	1	1	1	1	1					5
13		1	1	1				1		4
14	1	1	1	1						4
15	1	1								2
16		1	1	1		1		1	1	6
17	1	1	1	1	1	1	1	1	1	9
18		1	1	1	1					4
19	1			1	1	1	1	1	1	7
20					1	1	1	1	1	5
22						1				1
23	1	1	1	1	1			1	1	7
24					1	1	1			3
26				1						1
27					1	1	1	1	1	5
31						1				1
33						1				1
50								1		1
52									1	1
53		1	1							2
57					1	1	1	1	1	5
64								1	1	2
92								1	1	2
108									1	1
114								1	1	2
116							1	1	1	3
Total	**11**	**17**	**16**	**12**	**13**	**12**	**9**	**15**	**15**	**120**

2.6.3.2 Benthic Community Results

The benthic data resulting from the SF-DODS SMMP surveys are actually the first long-term assessment of large-scale, deep sea disposal events. Previous review articles on deep-sea recolonization (Pequegnat 1983; Thiel 2003) had no case studies except for shallow-water analogs and are largely speculative about the impacts of dredged material disposal. Pequegnat (1983) suspected that benthic impacts would be minimal from deep-sea disposal, and the results found at the SF-DODS have confirmed this prediction. However, the SF-DODS results differed from small-scale deep sea recolonization tray experiments in the western Atlantic using azoic sediment where recolonization was generally slow (Grassle 1977; Grassle and Morse-Porteous 1987). Recolonization at the SF-DODS was relatively rapid (less than 1 year), and the taxonomic composition of the communities found at the SF-DODS boundary and in the ambient sediments was not affected by small or moderate amounts of dredged material. In the center of the site, where the sediments would require recolonization after complete burial of the native fauna, ENSR (2005) found that the initial colonizers of disturbed sediments in the eastern Pacific were species from the ambient fauna found at control locations and not any unusual opportunistic species. *Prionospio delta* was the common and dominant spionid polychaete in the lower slope assemblages documented at the SF-DODS and appeared as one of the early colonizers along with foraminifera of the genus *Bathysiphon* (ENSR 2005).

The results from the seven years of benthic sampling at the SF-DODS following the start of disposal operations at the site showed that the benthic fauna at the SF-DODS and vicinity were highly resilient, and if dredged material were to stop for any prolonged interval of time, the benthic community should return to a pre-disposal assemblage with a relatively short period of time (2-3 years). The benthic results showed that disposal has not caused regional degradation outside the site or even on the boundaries of the site (ENSR 2005), and that the resident infauna are capable of reworking small amounts of dredged material and coping with larger deposits of material such as those found at the site center (Figure 12).

2.6.3.3. Benthic Community Discussion

While there have been numerous studies documenting the rate and pattern of benthic recolonization following seafloor disturbance (Rhoads et al. 1978; Santos and Simon 1980; Hall 1994) or dredged material disposal (Mauer et al. 1981a, 1981b, 1982, 1986; Scott et al. 1987; Harvey et al. 1998) in shallower coastal waters, there are few comparable studies of infaunal recolonization of deep-sea sediments in the eastern Pacific (ENSR 2005). The majority of the few deep sea recolonization studies that have been done have been carried out with trays of azoic sediment recovered over a series of time intervals after placement; while these tray recolonization experiments are the only practical way of studying recolonization on a small scale, they do introduce artifacts (hydrodynamic flow disturbance, separation of experimental sediments from natural substrata preventing recolonization by lateral or vertical burrowing) that render the results somewhat unrealistic for predicting recolonization response to dredged material disposal at depths such as those found at the SF-DODS. It was precisely this lack of information about benthic community response to a large scale disturbance in the deep sea that caused such a heightened concern during the site designation process and led to the comprehensive benthic monitoring program in the SMMP.

The results presented in ENSR (2005) provide an interpretation of the community structure present in the surface sediment samples. These data indicate that stations within the SF-DODS boundary that are affected by large volumes of dredged material appear to recolonize rapidly and by the same taxa that are normally found in the adjacent ambient sediments. The handful of recolonization studies that have been done in the western Atlantic generally have found that the colonizing species were not ones typically found in the ambient fauna. In contrast, the few recolonization studies done in the eastern Pacific deep sea (Levin and Smith 1984; Kukert and Smith 1992; Levin and DiBacco 1995) have found that the initial colonizers in disturbed or azoic sediments appear to be species that are relatively common in the surrounding sediment. The results from the SF-DODS support these other eastern Pacific studies and seem to indicate that deep sea recolonization patterns in the Pacific are quite different than those documented in the western Atlantic. One suggested reason for this apparent resiliency of the native fauna in the vicinity of the SF-DODS is because of the natural periodic slumping and turbidity flows that occur in this region of the slope (ENSR 2005); the resident infaunal taxa in this region may be pre-adapted to rapidly colonize areas of disturbed sediment.

This dataset is also valuable for allowing the evaluation of the background variability of community parameters at the site, in the hopes of understanding what level of sampling would be required to make solid inference regarding impacts from dredged material disposal. This was accomplished with a power analysis to determine the number of benthic samples per station that would be required to sufficiently characterize any changes in community parameters among stations.

2.6.3.4 Power Analysis of Benthic Results

The Tier 2 biological monitoring specified in the SMMP includes, "…*a comparison of the benthic community within the dredged material footprint to benthic communities in adjacent areas outside of the dredged material footprint. An appropriate time-series (ordinal) and community analysis shall be performed using data collected during the current year and previous years to determine whether there are adverse changes in the benthic populations outside of the disposal site which may endanger the marine environment.*" Similarly, Tier 3 biological monitoring includes, "…*advanced studies of benthic communities to evaluate how these populations might be affected by disposal site use. Such studies may include additional sampling stations, greater frequency of sampling, more advanced sampling methodologies or equipment, or other additional increased study measures compared to similar studies conducted in Tiers 1 or 2…*"

Implicit in the monitoring required in Tier 2 and Tier 3 is the ability to detect a change in benthic community structure between stations on dredged material and stations on ambient sediment. In order to accomplish this, the sampling design for monitoring the benthic infauna at the SF-DODS needs to be adequate for the intended data analyses. A power analysis for a pair wise comparison approach will be used to illustrate the level of sampling required to detect a reasonable change in benthic community metrics given the level of variability documented at the site from the nine years of benthic data summarized in the ENSR (2005) report. “Statistical power” is the probability of detecting a difference when a difference really exists. The power of a test can be calculated as a function of the sample size, the variance, the type I error level (α) and the “effect size” (Lipsey 1990). The effect size is the minimum difference between sample means that is expected to be statistically significant. If we fix α (at 5%) and the power (at 80%), and estimate variance, we can calculate the relationship between the sample size and the effect size. For a given number of samples per station, a very large effect size indicates that variability is so high that only very large changes would be detected.

We first needed an estimate of the within-station variability. The historic sampling design did not include multiple samples from single stations; therefore, the best estimate of intrinsic variability was based on a group of stations that were most similar to one another and did not have dredged material for two or more years. These stations may be considered as close to “ambient” conditions as possible for this deep water site. ENSR (2005) found that stations at or below the 2800m isobath were the most similar. We identified the stations within this depth range which had no or trace amounts of dredged material for two consecutive years in the SPI surveys. This automatically excluded the January 1996 samples, because we did not know exactly where the previous year’s dredged material was located. There were only four benthic stations that fit these criteria; these were:

- Station 23 in December 1996;
- Station 64 in September 2003;
- Station 92 in September 2002 and September 2003.

The standard deviation of these four stations was used as the background variance and to calculate the effect size of a two-sample, two-sided t-test comparing the means between two stations or between two time periods at a single station. The type I error rate (α) was set at 5%, and power was set at 80%. The relationship between sample size (number of replicates per station) and effect size (represented as a percent of the “ambient” mean value) was calculated for the following summary metrics:

- total individuals (all species, per $0.1m^2$),
- number of valid species,
- Pielou’s J,
- Fisher’s log-series a,
- Shannon’s H' (log 2).

Pielou’s and Shannon’s diversity indices had the lowest variability, and a typical design of five replicates per station would allow the detection of a difference between means equivalent to 10% or less of the ambient mean (Figure 21). The other metrics were more variable, and an effect size of 20% of the ambient mean required eight replicates per station (for Valid Species Count), and fifteen or sixteen replicate samples for Fisher’s alpha and Total Individuals, respectively. Five replicates at each station should achieve an effect size equivalent to 50% of the ambient means for the most variable endpoints.

2.6.3.5 Benthic Community Conclusions

The benthic monitoring performed between 1995 – 2007 at the SF-DODS has eliminated the concerns raised during the site designation process about the uncertainties with benthic community response to deep sea dredged material disposal: the dredged material is readily and rapidly recolonized by fauna from the species pool in the ambient sediment, and there has been no indication of any degradation of benthic community structure outside the site or in the surrounding area. We now know (similar to the results that have been documented in dredged material disposal sites in shallower water) that placing sediment that has passed the required testing for open-ocean disposal (EPA/USACE 1991) causes a temporary but reversible perturbation in benthic community structure; the new sediments are rapidly colonized by native taxa from the surrounding area, and the benthic community will recover to a pre-disposal assemblage through successional processes in a few years.

2.7 Confirmation Studies

The existing SMMP for the SF-DODS requires periodic confirmatory monitoring at least once every three years (EPA 1994). Samples collected from the dredged material footprint are collected and analyzed for bioassay and bioaccumulation testing following Green Book methods (EPA/USACE 1991). In addition, current meters, sediment traps and near-surface arrays of filter-feeding organisms (mussels) are required to be deployed for at least a month during active site use (see Section 2.2). The purpose of this monitoring was to confirm that: a). material disposed at the SF-DODS was in fact adequately represented by pre-disposal sampling and testing, and b). that no substantial bioaccumulation of sediment-associated contaminants may be occurring, especially within the boundaries of the Gulf of the Farallones National Marine Sanctuary, as a result of exposure to any suspended sediment plumes from multiple disposal events over time.

2.7.1 Bioassay and Bioaccumulation Results

In 1998, sediment was collected for bioassays from inside and outside the dredged material footprint (EPA 2002). Samples were collected from the top 10 cm of the boxcore (Figure 5); stations detected with dredged material present comprised the “Inside Footprint” composite, while stations without any apparent dredged material comprised the “Outside Footprint” composite. The samples were submitted for 10-day solid phase acute toxicity tests, and 28-day bioaccumulation tests.

The solid phase 10-day acute toxicity tests were conducted using the amphipod *Ampelisca abdita* and the polychaete *Nephthys caecoides*. The results showed that there was no significant acute toxicity to either the amphipods or polychaetes associated with the “Inside Footprint” samples. Toxicity was defined in the same way as in dredged material testing protocols: a sample was considered toxic if survival was statistically different from, and more than 10% (for the polychaete) or 20% (for the amphipod) less the negative control. The SF-DODS reference area was not sampled, so all comparisons were made to the more environmentally conservative negative control.

Bioaccumulation was evaluated from 28-day exposures with the clam *Macoma nasuta* and the same polychaete as in bioassay testing (*N. caecoides*). Tissue concentrations of a series of contaminants were measured, and comparisons were made between the sample and control tissues (unexposed organisms of each species), as well as between the “Inside” and “Outside” footprint samples. Results showed that most chemicals were not elevated in the dredged material samples relative to control or the off-site samples. In the *M. nasuta* samples, concentrations of chromium (Cr), PAHs, and DDT were statistically higher in tissues exposed to on-site samples relative to samples collected outside of the footprint. Similarly, lead and DDT were elevated in *N. caecoides* samples. Of these compounds, however, only Cr in *Macoma* tissue was outside the range found in the SF-DODS reference area database (USEPA 1999). For the few other values measured in tissue that were higher than in reference (HPAH in *N. caecoides*, and dieldrin in both species), there was no significant difference between the inside and outside footprint samples.

Although Cr was not elevated in the sediment or in tissues of the polychaete *N. caecoides*, it was elevated in tissues of the clam *M. nasuta* exposed to “Inside” sediments relative to both “Outside” and control tissues. The measured value (1.2 mg/kg wet weight) was higher than the range measured in *M. nasuta* tissues exposed to SF-DODS reference area sediment (0.2-0.5 mg/kg wet weight), and outside the range found in pre-disposal testing (0.22-0.5 mg/kg). The measured chromium value was compared against what little guidance there is for bioaccumulation in tissue, including the USACE Environmental Residue Effects Database (ERED) and was found to be within the range of “lowest observed effects.” The ERED, however, contains no Cr data specifically for *Macoma* or for other organisms that might be a more direct surrogate indicator for potential effects to benthic marine organisms. Confirmatory monitoring results, however, showed that the detection of a small number of very low concentrations of contaminants was restricted to the dredged material footprint itself.

2.7.2 Bioassay and Bioaccumulation Conclusions

There was no significant acute toxicity to either the amphipods or polychaetes associated with the “Inside Footprint” samples. There were a small number of very low, but elevated, concentrations of contaminants (relative to the negative control) present in the dredged material footprint.

2.7.3 Caged Mussel Bioaccumulation Results

Data from deployment of mussel arrays were intended to test whether substantial bioaccumulation of contaminants may be associated with exposure to suspended sediment plumes from multiple disposal events. Although the minimum time for deployment of the mussel arrays was one month, the mussels were deployed in November 1997 and retrieved a year later in November 1998, during one of the most intensive disposal periods (Table 1; both the Oakland and Richmond deepening projects were using the site simultaneously). Six bags of 50 mussels each were deployed on each of three moorings outside the disposal site at two depths (150m and 200m). After the year of exposure, mussels were collected and tissues analyzed for 11 metals, PCB congeners, pesticides, and PAHs.

Few compounds have established standards to which the tissue concentrations found in the deployed mussels could be compared. The US Food and Drug Administration (FDA) has published health based “Action Levels” in shellfish tissue for only seven compounds: methyl mercury, total PCB, and the pesticides Aldrin, Dieldrin, Endrin, Heptachlor, and Heptachlor epoxide. Four of these compounds were detected in mussel tissue from the SF-DODS Confirmatory Monitoring program (CDFG 2000). However, in each case, detected mussel tissue concentrations from the SF-DODS Confirmatory Monitoring program was one or more orders of magnitude lower than FDA Action Levels.

The SWRCB has developed “Maximum Tissue Residue Levels” (MTRLs) guidelines for comparison to data obtained from their Mussel Watch program; the MTRLs are derived by multiplying the human health based Water Quality Objective from the California Ocean Plan (SWRCB 1997) by a theoretical bioconcentration factor for each compound (for Aldrin, the MTRL was derived somewhat differently). As such, the MTRLs are considered by the SWRCB to represent concentrations at and below which human health would be protected from consumption of fish and shellfish.

Four of these compounds were detected in mussel tissues from the SF-DODS Confirmatory Monitoring program: Chlordane, DDT, Dieldrin, and total PCBs. Tissue concentrations of DDT from around the SF-DODS were lower than the calculated MTRLs. In contrast, tissue concentrations of Chlordane, Dieldrin, and total PCB were up to an order of magnitude higher than their MTRLs. However, for all three of these compounds, the actual concentrations in the mussels were only slightly above detection limits. More importantly, at all stations including the reference station mooring (R1), the bioaccumulated concentrations of these compounds were very similar to one another. These data may reflect either the organism background tissue concentration or a background level of exposure across the region. The main conclusion is that the caged mussel results indicate that proximity to the disposal site does not result in substantially greater exposure to contaminants than could be expected throughout the open ocean environment offshore of San Francisco Bay.

Another interesting finding was that the tissue levels measured in the mussels were generally similar to those in the clam *Macoma* exposed in the 28-day bioaccumulation test in reference site sediments. The primary exception was Cd, which was reported at 1-2 orders of magnitude higher in the mussels. Cadmium values, however, were essentially the same at all water column monitoring stations, including the reference site, and therefore most likely reflected background tissue levels.

2.7.4 Confirmation Studies Conclusion

Confirmatory monitoring was incorporated in the original SMMP as a safeguard against inadequate sampling or analysis of sediments permitted for disposal at the SF-DODS. The review of data from the last decade of monitoring has demonstrated that there have been very few elevated concentrations of contaminants measured in collected sediment from the SF-DODS, and the few questionable values have been primarily in samples from inside the site boundary. Suspended sediment plumes have not resulted in substantial or increased uptake of contaminants by water column organisms outside the SF-DODS boundary or within the Gulf of Farallones National Marine Sanctuary. This conclusion is based on results from monitoring during the 1997-1998 disposal season when extensive disposal occurred. Therefore the need for confirmatory monitoring is not warranted for routine SF-DODS monitoring. As stated above, a special study for confirmatory monitoring using appropriate and valid sampling designs and statistical methods could be conducted at any of the region’s open-water disposal sites.

PAGE LEFT INTENTIONALLY BLANK

3.0 SUMMARY OF CONCLUSIONS

Monitoring results from the SF-DODS (Section 2.0) produced the following conclusions:

- The thickest layers of dredged material have been confined within the designated site boundary.
- During each year of disposal, a thin apron of material has spread out to varying distances beyond the site boundary as predicted by the modeling. This apron has rarely exceeded 5 cm per year.
- Neither the thin yearly deposits, nor the thicker cumulative deposit outside the site boundaries have had any significant adverse impacts on the benthos.
- Based on SPI monitoring results, recolonization of the dredged material is very rapid both within and outside the site (much more rapid than expected at the time of the Site Designation EIS and development of the SMMP). The EIS predicted that offsite deposition would have no significant adverse physical impacts, and this has been demonstrated; furthermore, the rapid recovery of onsite stations has shown that deposits > 10 cm in a year have no long term adverse effects.
- The 5 cm thickness of deposits outside the site boundary defined in the EIS as a trigger for Tier 2 investigations or management actions has proven to be unnecessarily conservative, because no observable adverse impacts have occurred in areas outside the site having layers this thick; and recovery of even thicker deposits both inside and outside the site has been very rapid.
- No plumes of dredged material from the disposal site are reaching or adversely affecting the Gulf of Farallones Marine Sanctuary. Material found in sediment traps was determined to come from leaking disposal barges, not SF-DODS, and this source has been substantially reduced by separate EPA monitoring requirements and compliance actions.
- While the modeling results were accurate enough to predict the general pattern of sediment dispersion (verified by sediment trap and caged mussel studies) and dredged material footprint (verified by SPI results), the regional currents are variable enough so that more accurate model predictions of the dredged material footprint would only be obtained with real-time information on water currents. This eliminates the utility of using additional modeled output in the future to predict subsequent changes to the dredged material footprint (it is more cost-effective to just map the footprint than collect the water current data needed for predictive modeling which would still need verification)
- There is no difference in benthic recovery rates with variation in dredged material volume (Figure 21), indicating that the current annual disposal volume limit (4.8

mcy) is within the range of normal adaptive response to disturbance by the existing benthic community.

- Measured chemical concentrations in the sediment have generally not exceeded those background values found either at the site prior to disposal or at the SF-DODS reference area; the few chemical compounds whose concentrations have exceeded background values have still been well below any value to cause any potential concern for biological effects.
- There have been no adverse impacts to marine birds from disposal activities; the only effect observed was small and limited to the immediate vicinity of the disposal zone in the heaviest years.
- There have been no adverse impacts to marine mammals from disposal activities, most observed changes were attributed to regional water mass changes.
- There have been no adverse impacts to pelagic fish from disposal activities, most observed changes were attributed to regional water mass changes.
- Detailed analysis of 120 benthic samples revealed that stations within the SF-DODS boundary that are affected by large volumes of dredged material have recolonized rapidly and by the same taxa that are normally found in the adjacent ambient sediments; stations outside the disposal site with thin layers of material are similar to stations with no dredged material.
- Confirmation studies have shown no adverse biological effects from sediments collected from both inside and outside the site and subjected to both bioassay and bioaccumulation testing results.
- Caged mussel confirmation studies conducted at three different locations during high volume disposal events revealed that tissue concentrations of detected chemical compounds were similar to each other regardless of mooring location, and that proximity to the disposal site does not result in substantially greater exposure to contaminants than could be expected throughout the open ocean environment offshore of San Francisco Bay.
- The monitoring program produced a unique and extremely valuable dataset. The scientific and policy making communities have substantial data on deep benthic environments including recovery rates, adequacy of modeling, feasibility of site and confirmatory monitoring, and many new species have been described from the sampling effort.

4.0 REFERENCES CITED

Abdelrhman, M.A. 1992. Modeling of dredged material disposal in deep ocean environments near San Francisco: model intercomparison and exploration of modeling issues. Prepared for U.S. Environmental Protection Agency, San Francisco, Draft Report, 63 pp.

Bay, S.M., K.J. Ritter, D.E. Vidal-Dorsch, L.J. Field. 2007. Comparison of national and regional sediment quality guidelines for predicting sediment toxicity in California. Southern California Coastal Water Research Project. Costa Mesa, CA.

Bothner, M.H., P.W. Gill, W.S. Boothman, B.B. Taylor, and H.A. Karl. 1998. Chemical gradients in sediment cores from an EPA Reference Site off the Farallon Islands – assessing chemical indicators of dredged material disposal in the sea. Mar. Pol. Bull. 36(6):443-457.

Boudreau, B. P. 1998. Mean mixed depth of sediments: The wherefore and the why. Limnol. Oceanogr. 43: 524-526.

CDFG. 2000. Quality Assurance/Quality Control Document, USEPA Deep-Water Disposal Site. Department of Fish and Game, Marine Pollution Studies Laboratory, Moss Landing, CA. March 15, 2000. Prepared by G. Ichikawa, J. Goetzl, M. Pranger, A. Bonnema, and M. Stephenson.

Chin, J.L. and A. Ota. 2001. Disposal of dredged material and other waste on the continental shelf and slope. IN: Karl, H.A., J.L. Chin, E. Ueber, P.H. Stauffer, and J.W. Hendley II. Beyond the Golden Gate – Oceanography, Geology, Biology, and Environmental Issues in the Gulf of the Farallones. USGS Circular 1198 (full-length technical version), pp. 193-206.

Clarke, K.R. and R.N. Gorley. 2001. PRIMER v.5: User manual/tutorial. Plymouth Marine Laboratory, Plymouth, UK. 91 pp.

Dean, W.E. and J.V. Gardner. 2001. Chemical composition of surface sediments on the sea floor. IN: Karl, H.A., J.L. Chin, E. Ueber, P.H. Stauffer, and J.W. Hendley II. Beyond the Golden Gate – Oceanography, Geology, Biology, and Environmental Issues in the Gulf of the Farallones. USGS Circular 1198 (full-length technical version), pp. 101-115.

ENSR, 2005. Long-term benthic infaunal monitoring at the San Francisco Deep-Ocean Dredged Material Disposal Site (SF-DODS) (January 1996 – September 2003). Final Report submitted to US Environmental Protection Agency, Region IX, San Francisco, CA.

ENSR, 2006. San Francisco Deep Ocean Dredged Material Disposal Site (SF-DODS) Monitoring Program: September 2005. Final Report prepared for the Port of

Oakland and the U.S. Army Corps of Engineers, San Francisco District, 38 pp. + Appendices.

ENSR, 2007. San Francisco Deep Ocean Dredged Material Disposal Site (SF-DODS) Monitoring Program: September 2006. Final Report prepared for the Port of Oakland and the U.S. Army Corps of Engineers, San Francisco District, 72 pp. + Appendices.

ENSR, 2008. San Francisco Deep Ocean Dredged Material Disposal Site (SF-DODS) monitoring program: July 2007. Draft Report submitted to Department of the Army, San Francisco District, Corps of Engineers, San Francisco, CA.

EPA 1993. Final Environmental Impact Statement for Designation of a Deep Water Ocean Dredged Material Disposal Site off San Francisco, California. August, 1993.

EPA 1994. Final Rule. Ocean Dumping: Designation of a deep ocean dredged material disposal site (SF-DODS) located off San Francisco, CA. U.S. Environmental Protection Agency. 40 CFR Part 228. Federal Register, August 11, 1994.

EPA 1998. San Francisco Deep Ocean Disposal Site (SF-DODS) Site Management and Monitoring Plan Implementation Manual. Public Review Draft. U.S. Environmental Protection Agency, San Francisco, CA. February 6, 1998.

EPA 1999a. Final Rule. Ocean Dumping: Amendment of Site Designation. U.S. Enviromental Protection Agency. 40 CFR Part 228. Federal Register, July 23, 1999. (Volume 64, Number 141) http://www.epa.gov/fedrgstr/EPA-WATER/1999/July/Day-23/w18606.htm

EPA 1999b. Overview: Development of a Reference Area Database for the San Francisco Deep Ocean Disposal Site (SF-DODS). US EPA Region 9, San Francisco, CA.

EPA 2002. Monitoring Report for 1997 through 2000. San Francisco Deep Ocean Disposal Site (SF-DODS). October 28, 2002 Draft Version. US Environmental Protection Agency, Region 9, San Francisco, CA.

EPA/USACE. 1991. Evaluation of Dredged Material Proposed for Ocean Disposal - Testing Manual. EPA 503/8-91/001.

Fairey R, Long ER, Roberts CA, Anderson BS, Phillips BM, Hunt JW, Puckett HR, CJ Wilson. 2001. An evaluation of methods for calculating mean sediment quality guideline quotients as indicators of contamination and acute toxicity to amphipods by chemical mixtures. Environ Toxicol Chem 20:2276-2286.

Field, L.J., D.D. MacDonald, S.B. Norton, C.G. Ingersoll, C.G. Severn, D. Smorong, and R. Lindskoog. 2002. Predicting amphipod toxicity from sediments using Logistic Regression Models. Environ Toxicol Chem 9:1993-2005.

Fredette, T.J. and G. T. French. 2004. Understanding the physical and environmental consequences of dredged material disposal: history in New England and current perspectives. Marine Pollution Bulletin 49: 93-102.

Gardner, J.V., W.A. Dean, and P. Dartnell. 1997. Biogenic sedimentation beneath the California current system for the past 30 kyr and its paleooceanographic significance. Paleoceanography 12: 207-225.

Germano and Associates, Inc. 2004. An Evaluation of Existing Sediment Screening Guidelines for Wetland Creation/Beneficial Reuse of Dredged Material in the San Francisco Bay Area Along with a Proposed Approach for Alternative Guideline Development. Final Report. Funded by the California State Coastal Conservancy in cooperation with the Port of Oakland. February, 2004.

Grassle, J.F. 1977. Slow recolonization of deep-sea sediment. Nature 265: 618-619.

Grassle, J.F. and L. Morse-Porteous. 1987. Macrofaunal colonization of disturbed deep-sea environments and the structure of deep-sea benthic communities. Deep-Sea Research 34: 1911-1950.

Hall, S.J. 1994. Physical disturbance and marine benthic communities: life in unconsolidated sediments. Oceanog. Mar. Biol. Ann. Rev. 32: 179-239

Hamilton, P. 2001. Final Report. San Francisco Deep Ocean Disposal Site Modeling Studies. SAIC GSA Schedule Number 6S-35F-4461G, Special Item Number 132-51, Submitted to U.S. Environmental Protection Agency, San Francisco, CA.

Hamilton, P. and A. Y. Ota. 1993. Assessing effects for disposal sites off San Francisco, pp 14-26. IN: Estuarine and Coastal Modeling III, Proceedings of the 3rd International Conference, September 8-10, 1993, Oak Brook, IL ASCE.

Harvey, M., D. Gauthier and J. Munro. 1998. Temporal changes in the composition and abundance of the macro-benthic invertebrate communities at dredged material disposal sites in the Anse à Beaufils, Baie des Chaleurs, Eastern Canada. Mar. Poll. Bull. 36: 41-55.

Hickey, B.M. 1979. The California Current System – hypothesis and facts. Prog. Oceanogr. 8: 191-279

H.T. Harvey and Associates. 1998. Seabird and Marine Mammal Monitoring, SF-DODS Dredged Materials Disposal. Annual Report No. 2. Report Period: 1 November 1996 to 31 October 1997. Submitted to USACE San Francisco District, San Francisco, CA.

H.T. Harvey and Associates. 1999. Seabird and Marine Mammal Monitoring, SF-DODS Dredged Materials Disposal. Annual Report No. 3. Report Period: 1 November 1997 to 31 October 1998. Submitted to USACE San Francisco District, San Francisco, CA.

H.T. Harvey and Associates. 2000. Seabird and Marine Mammal Monitoring, SF-DODS Dredged Materials Disposal. Annual Report No. 4. Report Period: 1 November 1998 to 31 October 1999. Submitted to USACE San Francisco District, San Francisco, CA.

H.T. Harvey and Associates. 2001. Seabird and Marine Mammal Monitoring, SF-DODS Dredged Materials Disposal. Annual Report No. 5. Report Period: 1 November 1999 to 31 October 2000. Submitted to USACE San Francisco District, San Francisco, CA.

H.T. Harvey and Associates. 2002. Draft report, Seabird and Marine Mammal Monitoring, SF-DODS Dredged Materials Disposal. Annual Report No. 6. Report Period: 1 November 2000 to 31 October 2001. Submitted to USACE San Francisco District, San Francisco, CA.

Hurlbert, S. H. 1971. The nonconcept of species diversity: a critique and alternative parameters. Ecology 52: 577-586.

Johnson, B.H. 1990. User's Guide for Models of Dredged Material Disposal in Open Water, Technical Report D-90-5, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Karl, H.A. 2001. Sediment of the sea floor. IN: Karl, H.A., J.L. Chin, E. Ueber, P.H. Stauffer, and J.W. Hendley II. Beyond the Golden Gate – Oceanography, Geology, Biology, and Environmental Issues in the Gulf of the Farallones. USGS Circular 1198 (full-length technical version), pp. 90-100.

Kukert, H. and C.R. Smith. 1992. Disturbance, colonization, and succession in a deep-sea sediment community: artificial mound experiments. Deep-Sea Research 39: 1349-1471.

Levin, L.A. and C. DiBacco. 1995. Influence of sediment transport on short-term recolonization by seamount infauna. Marine Ecology Progress Series 123: 163-175.

Levin, L.A. and C.R. Smith. 1984. Response of background fauna to disturbance and enrichment in the deep sea: a sediment tray experiment. Deep-Sea Research 31: 1277-1285.

Lipsey, M. W. 1990. Design sensitivity: Statistical power for experimental research. Newbury Park, CA: Sage Publications.

Long ER, MacDonald DD, Smith SL, Calder FD. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environ Manag 19:81-97LTMS. 1996. Long-Term Management Strategy (LTMS) for the Placement of Dredged material in the San Francisco Bay Region, Draft Policy Environmental Impact Statement/Programmatic Environmental Impact Report. Prepared by USACE San Francisco District, US EPA Region 9, San Francisco RWQCB, San Francisco BCDC, and California SWRCB.

LTMS. 1998. Long-Term Management Strategy (LTMS) for the Placement of Dredged Material in the San Francisco Bay Region, Final Policy Environmental Impact Statement/Programmatic Environmental Impact Report. Prepared by USACE San Francisco District, US EPA Region 9, San Francisco RWQCB, San Francisco BCDC, and California SWRCB.

Maurer, D., R. T. Keck, J.C. Tinsman, and W.A. Leathem. 1981a. Vertical migration and mortality of benthos in dredged material: Part I – Mollusca. Mar. Env. Res. 4: 299-319.

Maurer, D., R. T. Keck, J.C. Tinsman, and W.A. Leathem. 1981b. Vertical migration and mortality of benthos in dredged material: Part II – Crustacea. Mar. Env. Res. 5: 301-317.

Maurer, D., R. T. Keck, J.C. Tinsman, and W.A. Leathem. 1982. Vertical migration and mortality of benthos in dredged material: Part III – Polychaeta. Mar. Env. Res. 6: 49-68.

Maurer, D., R.T. Keck, J.C. Tinsman, W.A. Leathem, C. Wethe, C. Lord, and T.M. Church, 1986. Vertical migration and mortality of marine benthos in dredged material: a synthesis. Internationale Revue der gesamten Hydrobiologie, 71: 49-63.

McGowan, M., A. Marchi, J. Tustin, C. McCandlish, A. Abel, L. Light, and R. Dugdale. 2001. SF-DODS upper water column monitoring data report for 1998 and 1999 with preliminary analyses of the time series for 1996-1999. Report from Romberg Tiburon Center for Environmental Studies, San Francisco State University. Prepared for US Army Corps of Engineers, San Francisco District, San Francisco, CA. December 2000, Revised June 2001.

McGowan, M., C. McCandlish, A. Good, A. Marchi, J. Tustin, and R. Dugdale. 2003. SF DODS upper water column monitoring in 2000 and 2001. Report from Romberg Tiburon Center for Environmental Studies, San Francisco State University. Prepared for US Army Corps of Engineers, San Francisco District, San Francisco, CA.

Michelsen, T.C. 1999. Error rate minimization techniques for calculating sediment quality guidelines. Presentation at SETAC North American Conference, 2003, Philadelphia, PA. Avocet Consulting, Kenmore, WA.

Moore, D.W., R. Baudo, J.M. Conder, P.F. Landrum, V.A. McFarland, J.P. Meador, R.N. Millward, J.P.Shine, and J.Q. Word. 2002. Bioaccumulation in the assessment of sediment quality: uncertainty and potential application, pp 429-495, **IN**: Wenning, R. J., G.E. Batley, C.G. Ingersoll, and D.W. Moore (Eds). Use of Sediment Quality Guidelines and Related Tools for the Assessment of Contaminated Sediment. Proceedings from the Pellston Workshop, 18-22 August 2002, Fairmont, Montana. Setac Press.

Newell, R.C., L. J. Seiderer, and D.R. Hitchcock. 1998. The impact of dredging works in coastal waters: A review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed. Oceanography and Marine Biology: An Annual Review. 36: 127-178.

Noble, M.A., J. Xu, J. Kolak, A.L. Gartner, and K. Rosenberger. 2001. Measurements of slope current and environmental geochemistry near the western boundary of the Gulf of Farallones National Marine Sanctuary. U. S. Geological Survey, Menlo Park, CA. Open-File Report 2006-1288.

Pequegnat, W.E. 1983. Some aspects of deep ocean disposal of dredged material, pp 2298-252 IN: Kester, D.R., B.H. Ketchum, I.M. Duedall, and P.K. Park (eds.). Wastes in the Ocean, Vol.2. New York, John Wiley.

PRC Environmental Management, Inc. 1995. Final report for the midpoint monitoring of sediment dispersion and deposition at the Navy's ocean dredged material disposal site west of the Farallon 82 Islands, California. Report prepared by PRC Environmental Management, Inc. under Navy CLEAN Contract No. N62474-88-D-5086.

Rhoads, D.C., and J.D. Germano, 1982. Characterization of benthic processes using sediment profile imaging: An efficient method of Remote Ecological Monitoring Of The Seafloor (REMOTS^{TM} System). Marine Ecology Progress Series 8: 115-128.

Rhoads, D.C., and J.D. Germano. 1986. Interpreting long-term changes in benthic community structure: a new protocol. Hydrobiologia 142: 291-308.

Rhoads, D.C., and J.D. Germano. 1990. The use of REMOTS imaging technology for disposal site selection and monitoring, pp 50-64, IN Geotechnical Engineering of Ocean Waste Disposal [K. Demars and R. Chaney, eds.] ASTM Symposium Volume, January, 1989, Orlando, Fla., pp. 50-64.

Rhoads, D.C., P.L. McCall, and J.Y. Yingst. 1978. Disturbance and production on the estuarine seafloor. American Scientist 66: 577-586.

Roberts, D., S. Ralston, R. Springborn, K. Sakuma, A. McCall, and D. Woodbury. 1998. Results of the Second Year of Monitoring Studies at the San Francisco Deep Ocean Disposal Site to Assess the Possible impacts of the Disposal of Dredged materials on Selected Taxa of the Upper Water Column. Prepared for the USACE San Francisco District by the Groundfish Analysis Branch, Tiburon Laboratory, NMFS. Tiburon, CA.

SAIC. 1991. Biological and Sedimentological Investigations of the Sea Floor at the proposed U.S. Navy 103 Ocean Disposal Site. Final. Submitted by SAIC, Woods Hole, MA and Bothell, WA to PRC Environmental Management, Inc., San Francisco, CA.

SAIC. 1992a. Benthic Ecology and Sediment Characterization Ocean Studies Report. Detailed physical and biological oceanographic studies for an ocean site designation effort under the Marine Protection, Research and Sanctuaries Act of 1972 (MPRSA). Final Report prepared by Science Applications International Corporation for EPA Region IX under EPA Contract No. 68-C8-0062.

SAIC, 1992b. Modeling potential deposition and water column turbidity for proposed long-term disposal of dredged material at sites off San Francisco, California. Prepared for U.S. Environmental Protection Agency, Draft Final Report, 122 pp.

SAIC, 1996. San Francisco Deep Ocean Dredged Material Disposal Site (SF-DODS) Monitoring Program. Physical, Chemical, and Benthic Community Monitoring, January 1996. Final Report, October 16, 1996. Prepared for USACE, San Francisco District, San Francisco, CA.

SAIC, 1999a. San Francisco Deep Ocean Disposal Site (SF-DODS) Monitoring Program: Physical, Chemical, and Benthic Community Monitoring, December 1996. Final Report. Submitted to USACE, San Francisco District, San Francisco, CA.

SAIC, 1999b. San Francisco Deep Ocean Disposal Site (SF-DODS) Monitoring Program: Physical, Chemical, and Benthic Community Monitoring, October-November 1997. Final Report. Submitted to USACE, San Francisco District, San Francisco, CA.

SAIC, 2009. San Francisco Deep Ocean Disposal Site (SF-DODS) Monitoring Program: Physical, Chemical, and Benthic Community Monitoring – July 2008. Final Data Report. Submitted to USACE, San Francisco District, San Francisco, CA.

SAIC, ENSR, & GANDA. 2003. San Francisco Deep-Ocean Dredged Material Disposal Site (SF-DODS) Monitoring Program. Physical, Chemical, and Benthic Community Monitoring September 2002. Final Report to Dept. of the Army, San Francisco District Corps of Engineers. 106 pp. + appendices.

SAIC, ENSR, & GANDA. 2004. San Francisco Deep-Ocean Dredged Material Disposal Site (SF-DODS) Monitoring Program. Physical, Chemical, and Benthic Community Monitoring September 2003. Final Report to Dept. of the Army, San Francisco District Corps of Engineers. 100 pp. + appendices.

SAIC, ENSR, & GANDA. 2005. San Francisco Deep Ocean Dredged Material Disposal Site (SF-DODS) Monitoring Program. Physical, Chemical, and Benthic Community Monitoring September-October 2004. Final Report. Submitted to Department of the Army, San Francisco District, Corps of Engineers, San Francisco, CA. Submitted by Science Applications International Corporation, Bothell, WA, in association with ENSR Marine & Coastal Center, Woods Hole, MA, on behalf of Garcia and Associates, San Anselmo, CA. July 27, 2005.

Sanders, H.L. 1968. Marine benthic diversity: A comparative study. American Naturalist 102: 243-282.

San Francisco Estuary Institute (SFEI) 2007. The 2006 RMP Annual Monitoring Results. San Francisco Estuary and the Regional Monitoring Program for Water Quality in the San Francisco Estuary. SFEI Contribution 542. San Francsico Estuary Institute, Oakland, CA.

Santos, S. L. and J. L. Simon. 1980. Response of soft-bottom benthos to annual catastrophic disturbance in a south Florida estuary. Mar. Ecol. Prog. Ser. 3: 347-355.

Scott, J., D. Rhoads, J. Rosen, S. Pratt, and J. Gentile. 1987. Impact of Open-Water Disposal of Black Rock Harbor Dredged Material on Benthic Recolonization at the FVP Site. Technical Report D-87-4, NTIS No. AD-A184 166. Prepared for U.S. Army Engineer Waterways, Experiment Station by Science Applications International Corporation, Computer Sciences Corporation, University of Rhode Island, and U.S. Environmental Protection Agency.

SWRCB (State Water Resources Control Board). 1997. California Ocean Plan -Water Quality Control Plan, Ocean Waters of California. July 23, 1997. State Water Resources Control Board, California Environmental Protection Agency, Sacramento, California.

SWRCB. 2000. *State Mussel Watch Program, 1995-1997 Data Report*. Prepared by Del Rasmussen, Division of Water Quality, State Water Resources Control Board, California Environmental Protection Agency, Sacramento, CA.

SWRCB. 2007. Draft Staff Report. Water Quality Control Plan for Enclosed Bays and Estuaries. Part 1. Sediment Quality. State Water Resources Control Board, California Environmental Protection Agency. September 27, 2007.

TetraTech, 1992. Preliminary modeling for the purpose of estimating dredged material accumulations at deep ocean disposal sites off the Farallon Islands. Prepared for U.S. Environmental Protection Agency, San Francisco. Draft Final Report, 122 pp.

TetraTech. 1999. San Francisco Deep Ocean Dredged Material Disposal Site (SF-DODS) Monitoring Program. Physical, Chemical, and Benthic Community Monitoring, October 1998. Submitted to USACE, San Francisco District, San Francisco, CA.

TetraTech. 2000. San Francisco Deep Ocean Dredged Material Disposal Site (SF-DODS) Monitoring Program. Physical, Chemical, and Benthic Community Monitoring, October 1999. Draft Report. Submitted to USACE, San Francisco District, San Francisco, CA.

TetraTech. 2001. San Francisco Deep Ocean Disposal Site (SF-DODS) Monitoring Program: Physical, Chemical, and Benthic Community Monitoring, October 2000. Draft Report. Submitted to USACE, San Francisco District, San Francisco, CA.

TetraTech. 2002. San Francisco Deep Ocean Disposal Site (SF-DODS) Monitoring Program: Physical, Chemical, and Benthic Community Monitoring, October 2001. Final Report. Submitted to USACE, San Francisco District, San Francisco, CA. August 2002.

Thiel, H. 2003. Anthropogenic impacts on the deep sea, pp. 427-471 IN: Tyler, P.A. (ed.), Ecosystems of the Deep Oceans. Ecosystems of the World 28. Elsevier.

Vidal, D.E. and S. M. Bay. 2005. Comparative sediment guideline performance for predicting sediment toxicity in southern California, USA. Environ Toxicol Chem 24:3173-3182.

Washington Department of Ecology. 2007. Multiyear PBT Chemical Action Plan Schedule. Final. Department of Ecology Publication No. 07-07-016. Available on-line at: http://www.ecy.wa.gov/biblio/0607025.html.

Word, J.Q., B. B. Albrecht, M.L. Anghera, R. Baudo, S.M. Bay, D.M Di Toro, J.L. Hyland, C.G. Ingersoll, P.F. Landrum, E.R. Long, J.P. Meador, D.W. Moore, T.P. O'Connor, J.P.Shine. 2002. Predictive ability of sediment quality guidelines, pp. 121-161, **IN**: Wenning, R. J., G.E. Batley, C.G. Ingersoll, and D.W. Moore (Eds). Use of Sediment Quality Guidelines and Related Tools for the Assessment of Contaminated Sediment. Proceedings from the Pellston Workshop, 18-22 August 2002, Fairmont, Montana. Setac Press.

PAGE INTENTIONALLY LEFT BLANK

FIGURES

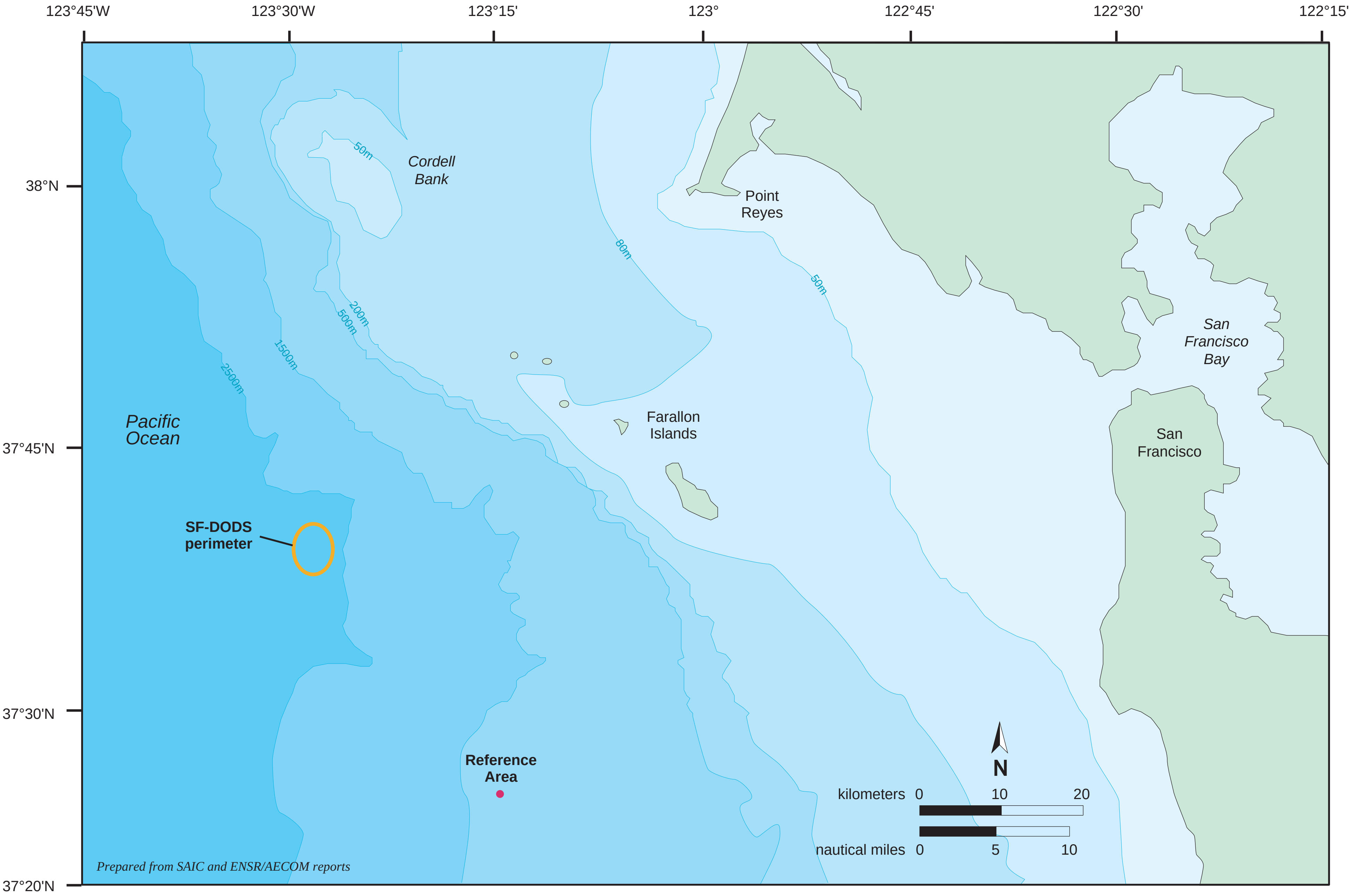


Figure 1: Location of San Francisco Deep Ocean Disposal Site (SF-DODS).

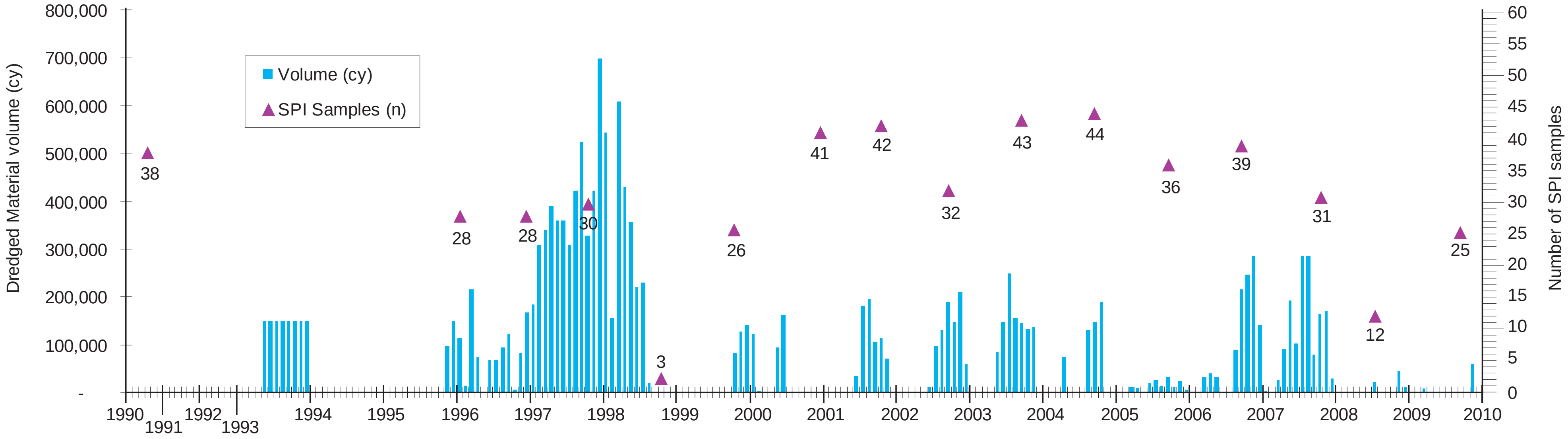


Figure 2: Monthly disposal volumes in cubic yards (bars) compared with date of monitoring surveys and number of SPI stations sampled (triangles). Total volumes are provided in Table 1. The totals are all bin volumes (estimated from the barge volume), in units of cubic yards. Bin volumes are likely greater than *in situ* volumes due to bulking and water entrainment caused by the dredging process. The estimates were obtained as follows. The Navy project estimated volume was obtained from that project. The volumes from 1995-1999 were obtained by summing the reported bin volumes from monthly project monitoring reports and as reported by the EPA (EPA 2002). Volume estimates from 2000-2003 were based on the silent inspector system used during those years (ADISS, or Automated Disposal Surveillance System), except for dredging in Oakland 2002, which was derived from the dredging contractor's records. Volume estimates from 2004-2009 were based on the silent inspector system used during those years (eTrac). Individual project sums are available in Appendix 3.

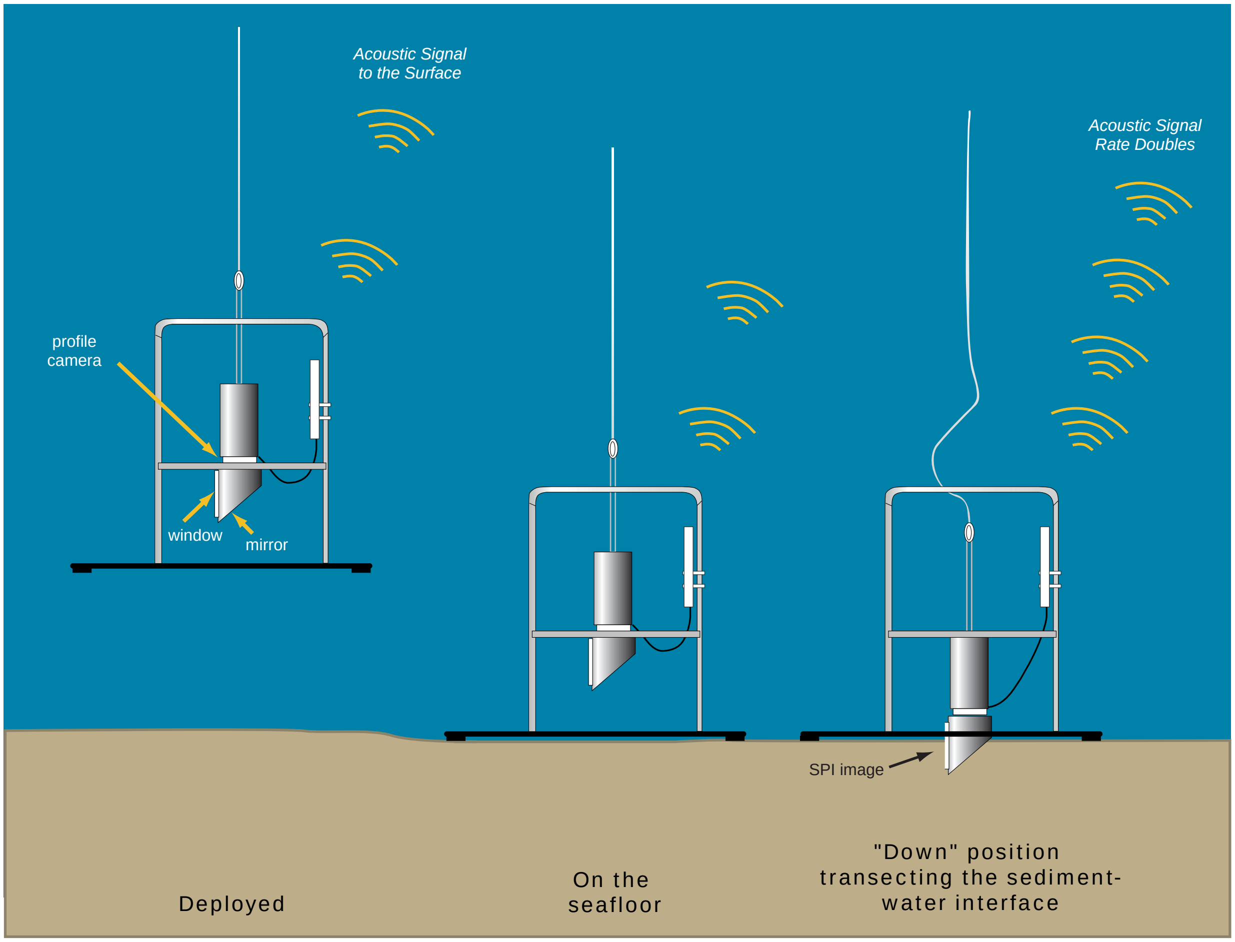
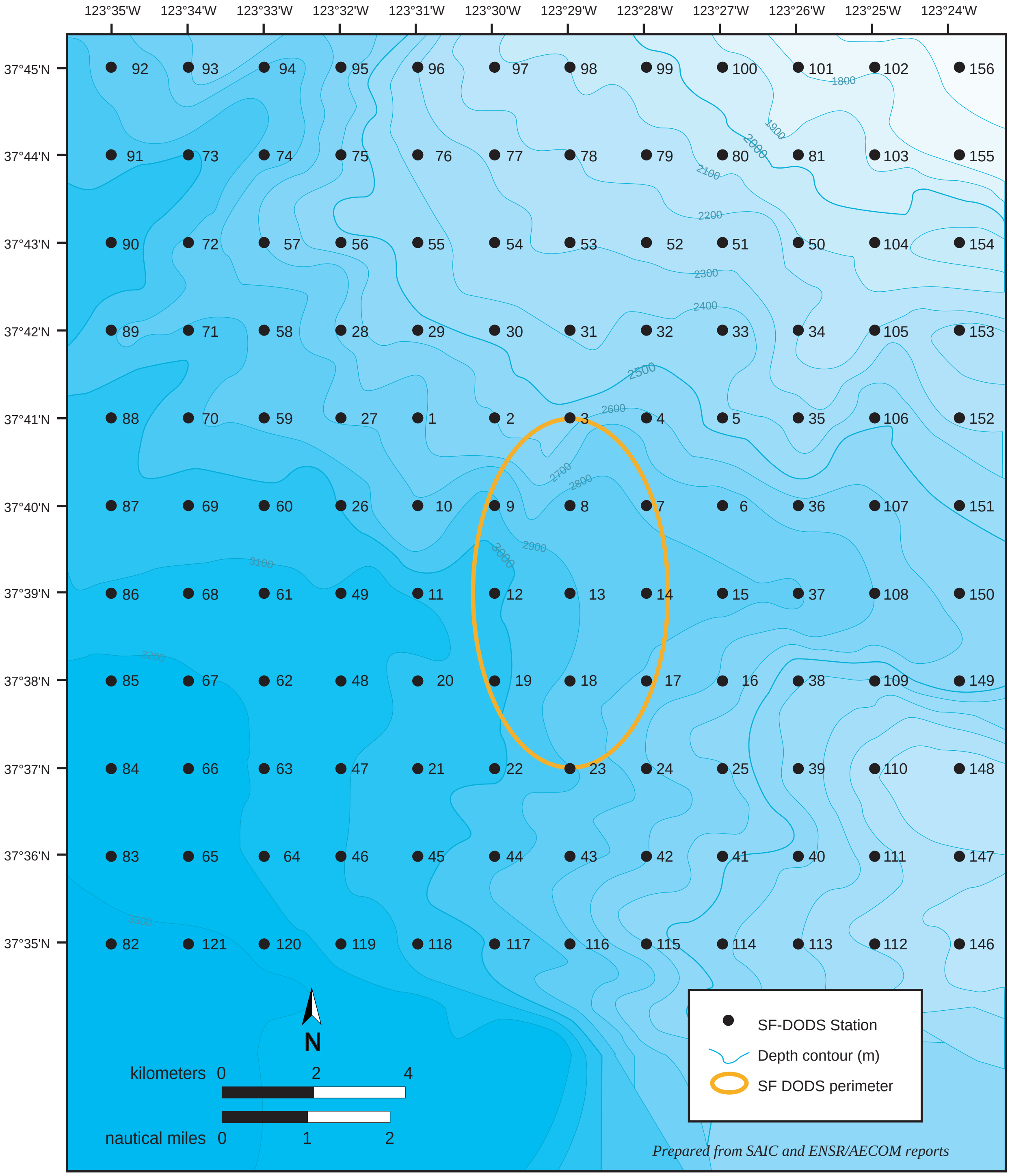
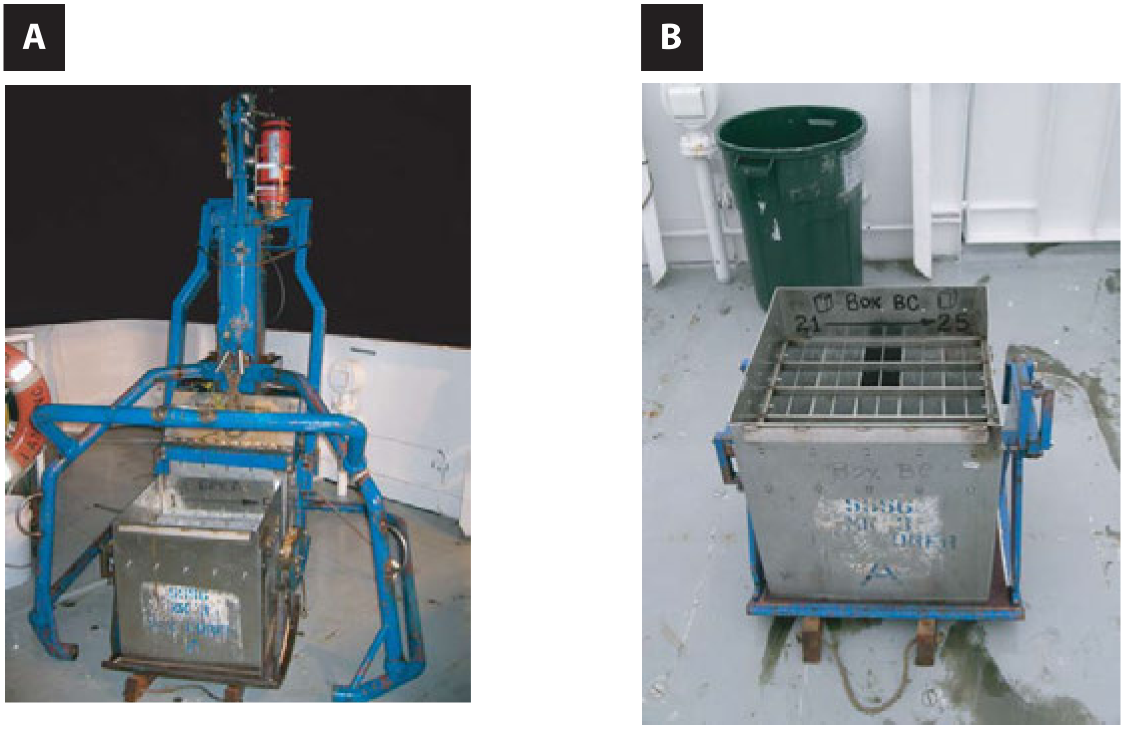


Figure 3: Deployment and operation of the sediment profile imaging (SPI) system; acoustic pinger signal doubles for 10 seconds after strobe is fired to signal successful image acquisition in deep-water operations.



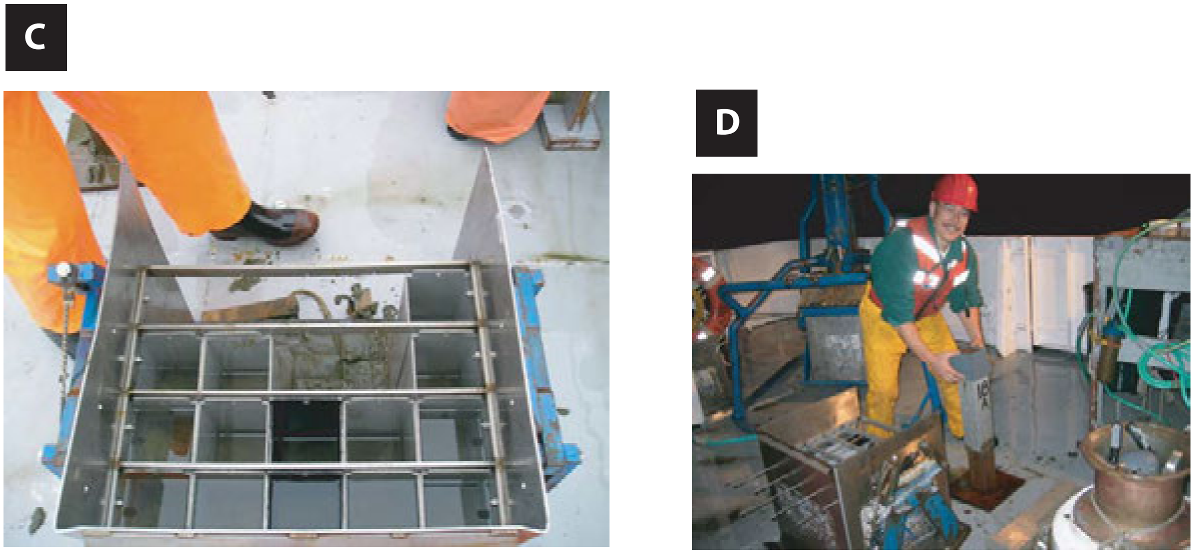
Prepared from SAIC and ENSR/AECOM reports

Figure 4: Sampling location grid for SF DODS monitoring surveys.



The 0.25 m² Sandia MK-III box corer

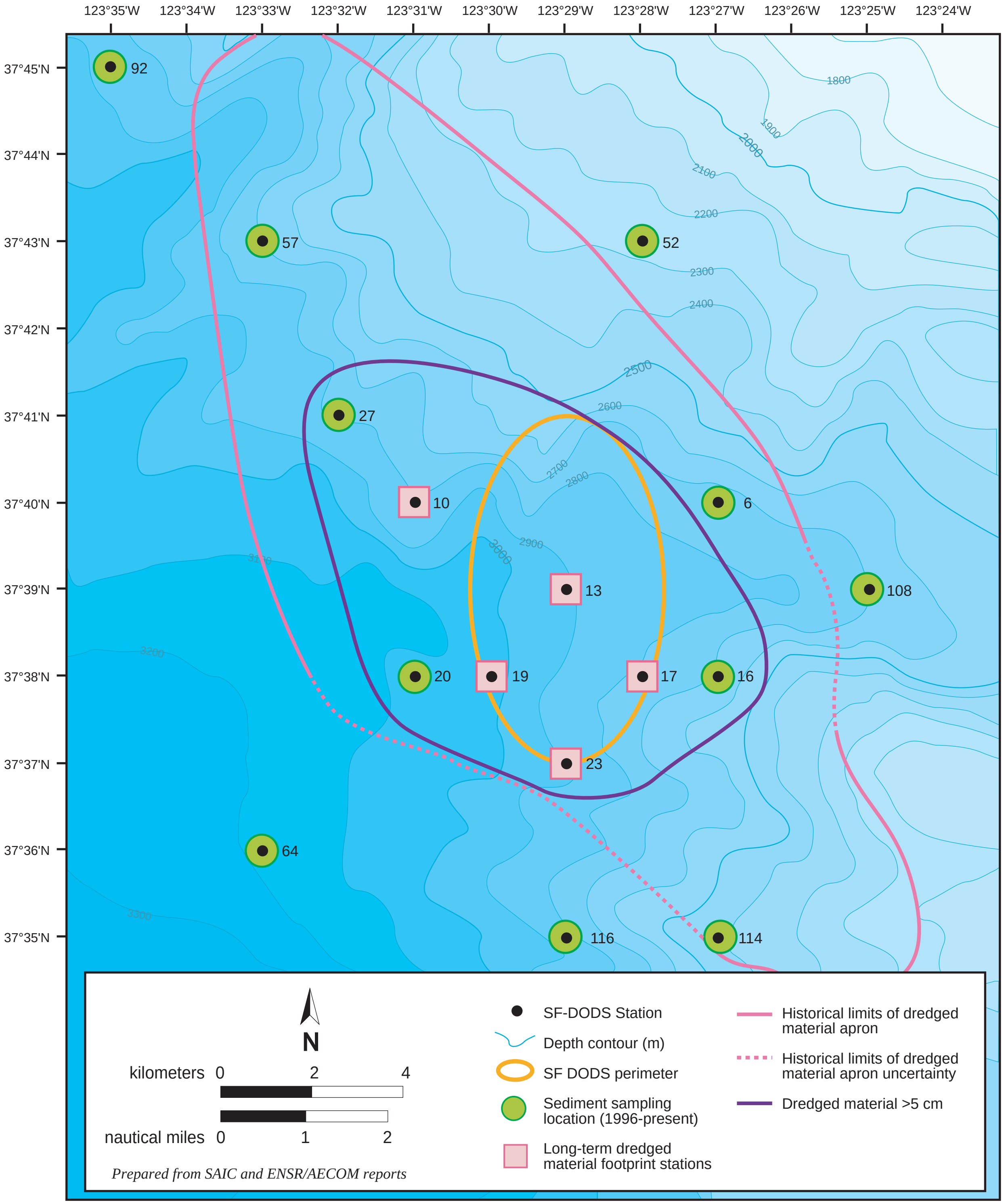
Detail of the partitioned box core showing the 25 subcores (10 x 10 cm).



Some of the subcores have been removed for chemistry and biology samples.

Sediment being extruded for processing from one of the subcores.

Figure 5: Equipment used to collect sediment samples during past monitoring surveys at SF-DODS.



Prepared from SAIC and ENSR/AECOM reports

Figure 6: Core locations most commonly sampled for sediment chemistry during the entire period of monitoring at the SF-DODS from 1996-present (circles), including the five long-term dredged material footprint stations (squares).

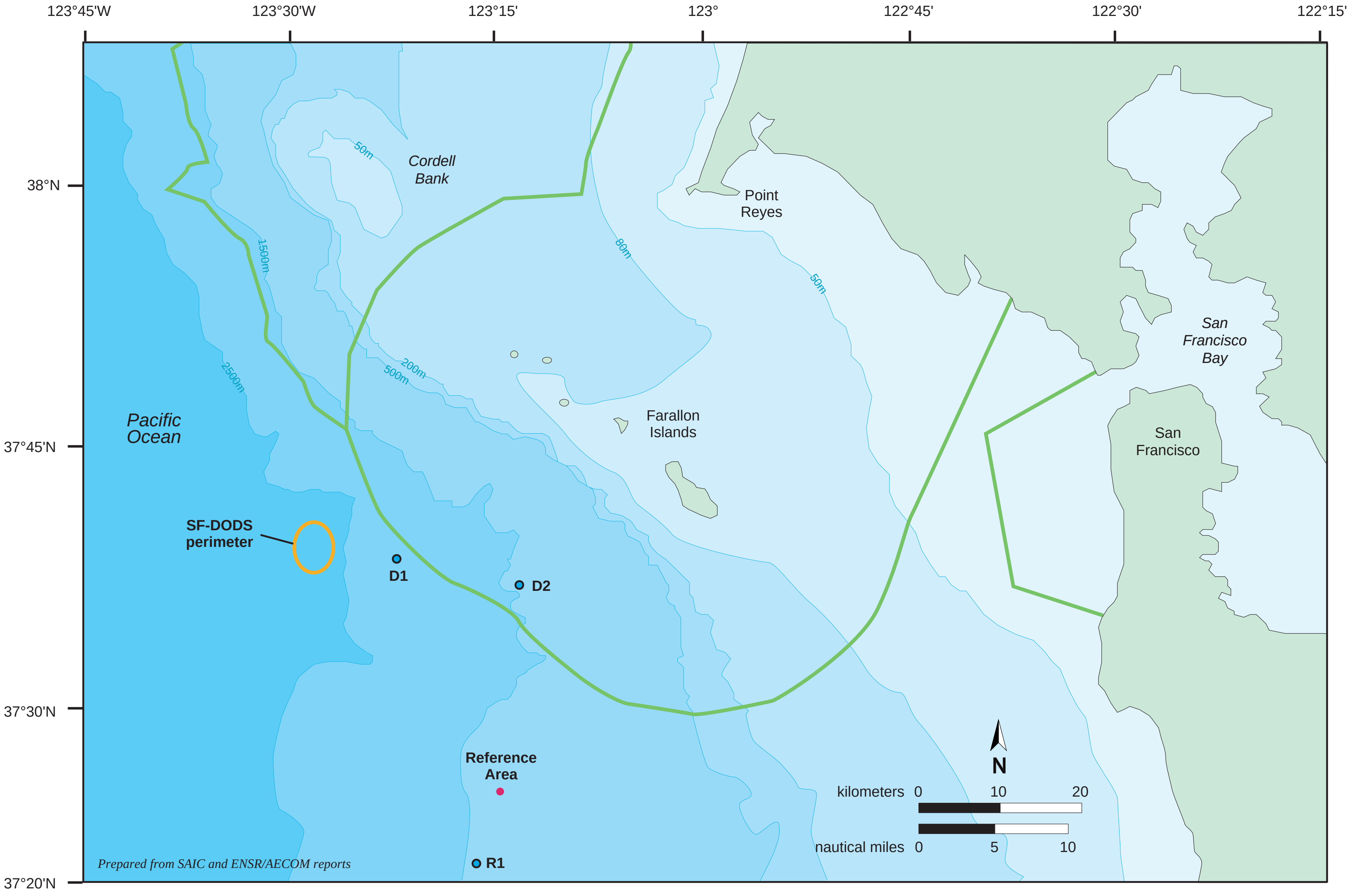


Figure 7. Location of the current meter and sediment trap moorings deployed by USGS from November 1997 to November 1998. Borders in green indicate boundaries of the Gulf of the Farallones National Marine Sanctuary.

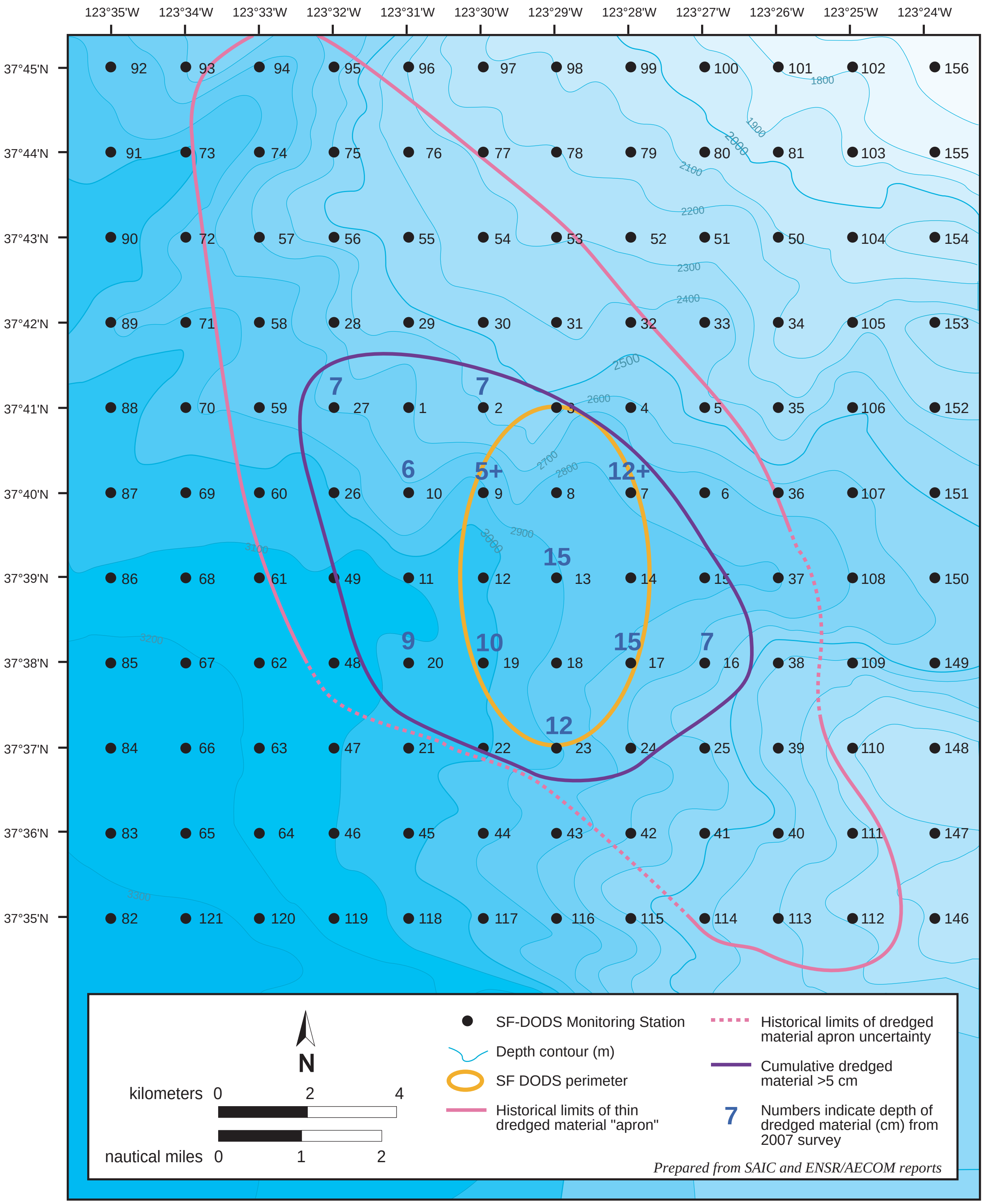
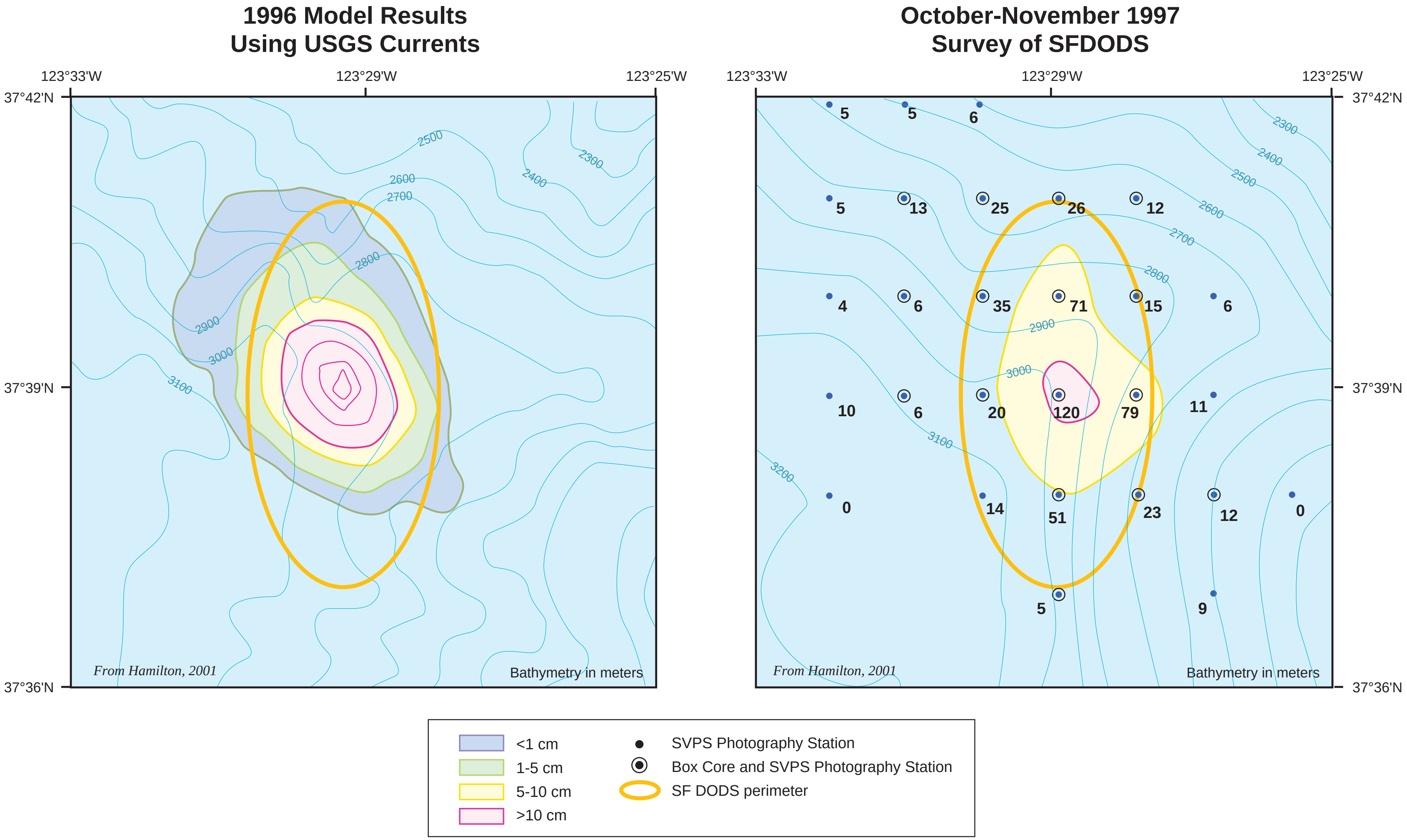


Figure 8: Summary compilation of dredged material thickness maps from all surveys between 1996-2009. Cumulative line represents all areas where dredged material has been detected > 5 cm thick. Large numbers at stations indicate depth of dredged material (cm) from 2007 survey.



1996 Model Results Using USGS Currents

October-November 1997 Survey of SFDODS

From Hamilton, 2001

Figure 9: Left Panel: Deposition (cm) from model year 1996 using USGS current data. Contours are 1, 2, 5, 10, 20, 30, and 34.3 cm. Right Panel: Distribution of recently placed dredged material from the October-November 1997 sediment survey of SFDODS. Station thicknesses are in cm. Survey data is from SAIC (1999b).

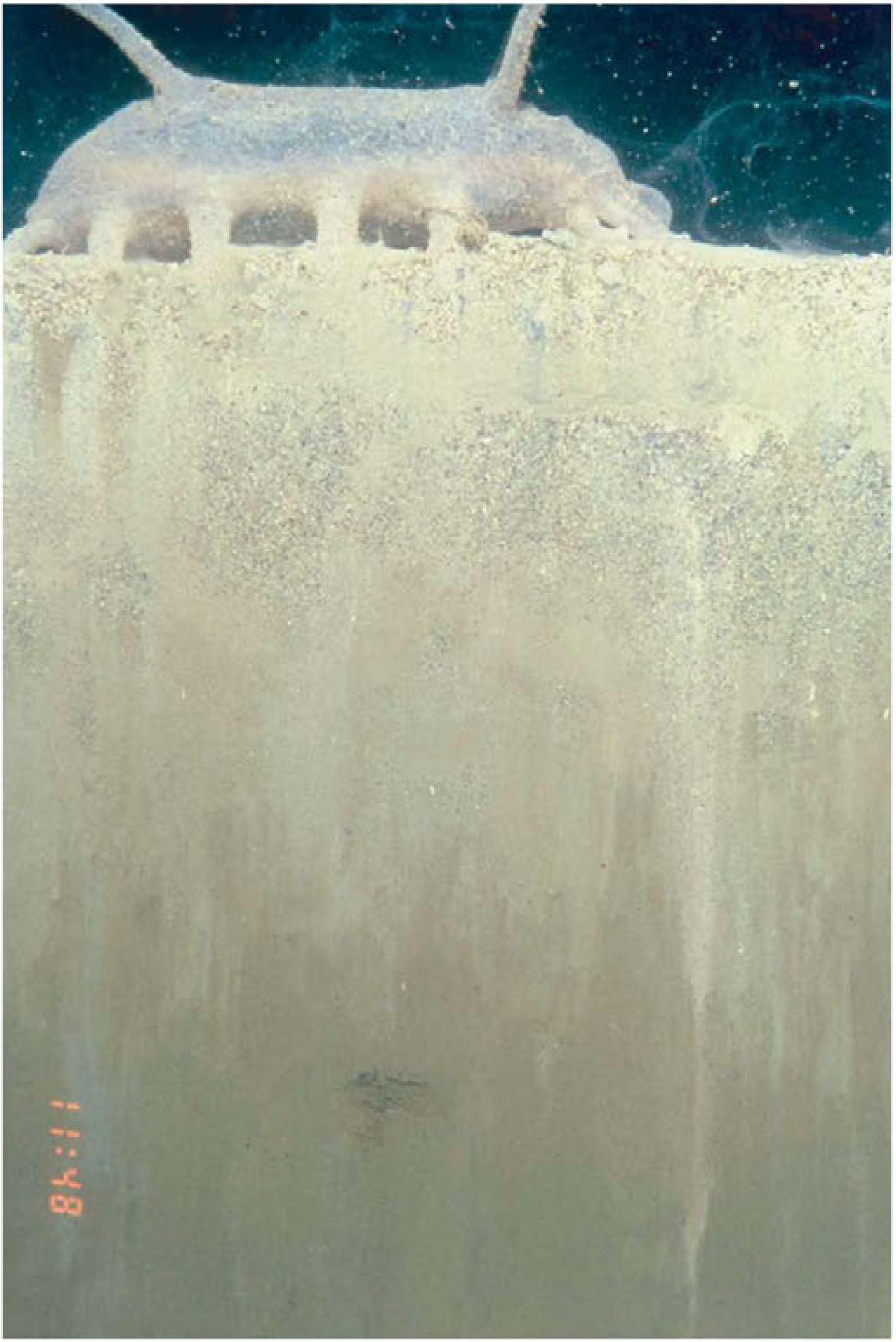


Figure 10: Sediment profile image from SFDODS taken within the boundary during the 1997 survey (Station 9) within the boundary shows evidence of a distinct layer of dredged material and an epibenthic animal grazing on the surface (elasapoid holothurian, *Scotoplanes globosa*). Scale: width of profile image = 14.5 cm.

Figure 11: Sediment profile image from north of SFDODS taken during the 1996 survey (Station 31) shows ambient sediment without dredged material. Scale: width of profile image - 14.5 cm.

Figure 12: This sediment profile image from the center of SF-DODS taken during the 2006 survey (Station 13) shows evidence (burrows, voids, and portions of worms against the faceplate) of Stage 3 taxa at depth (arrows) even though dredged material thickness exceeds the height of the camera's prism. Scale: width of profile image = 14.5 cm.

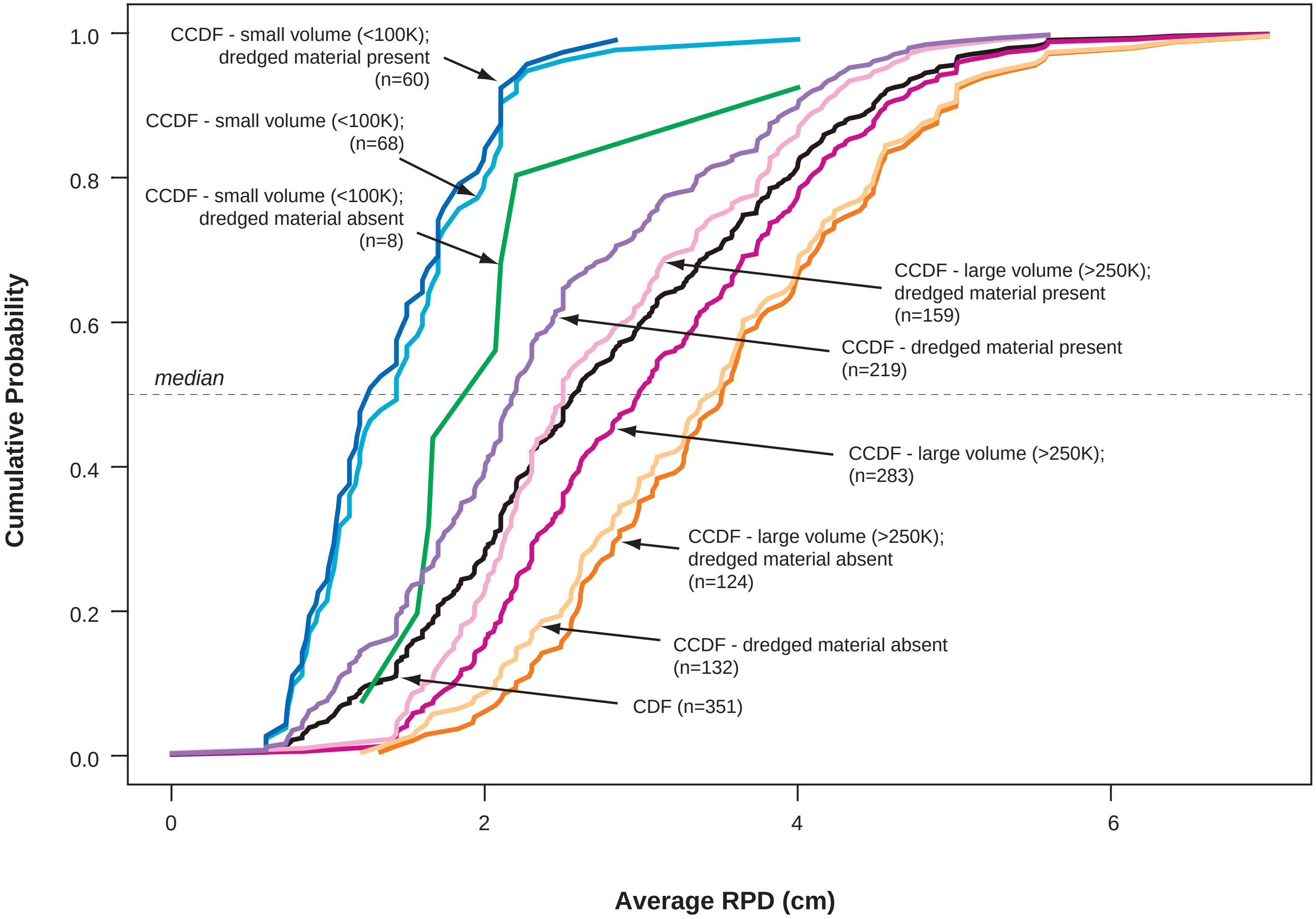


Figure 13: Empirical Cumulative Distribution Function (CDF) and Conditional Cumulative Distribution Functions (CCDF) curves for the RPD endpoint. Curves that are further to the right have a higher median RPD value for the distribution (i.e. generally better conditions), and steeper curves indicate distributions with less variability.

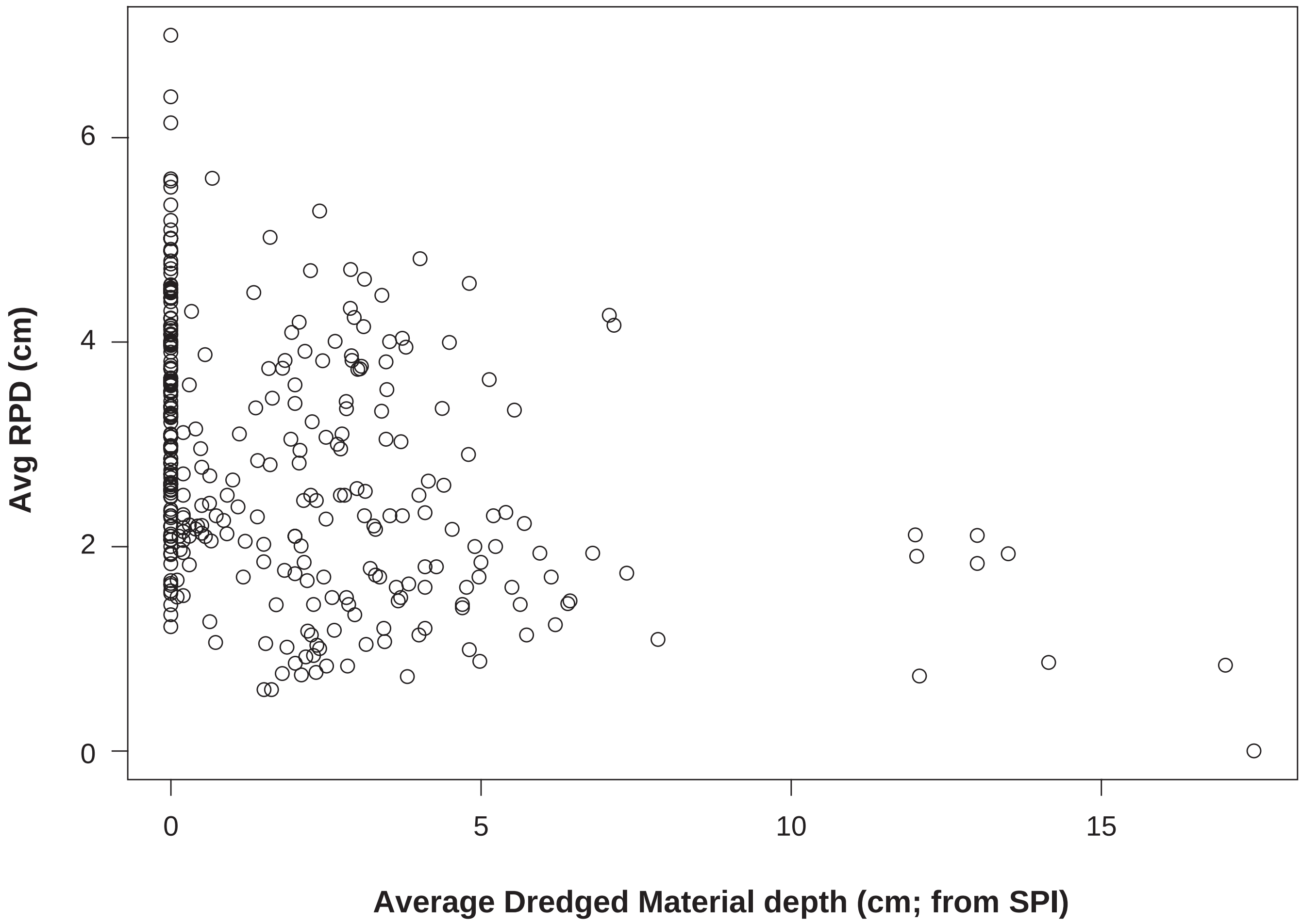


Figure 14: Relationship between Average Dredged Material depth and Average RPD, as measured in SPI surveys.

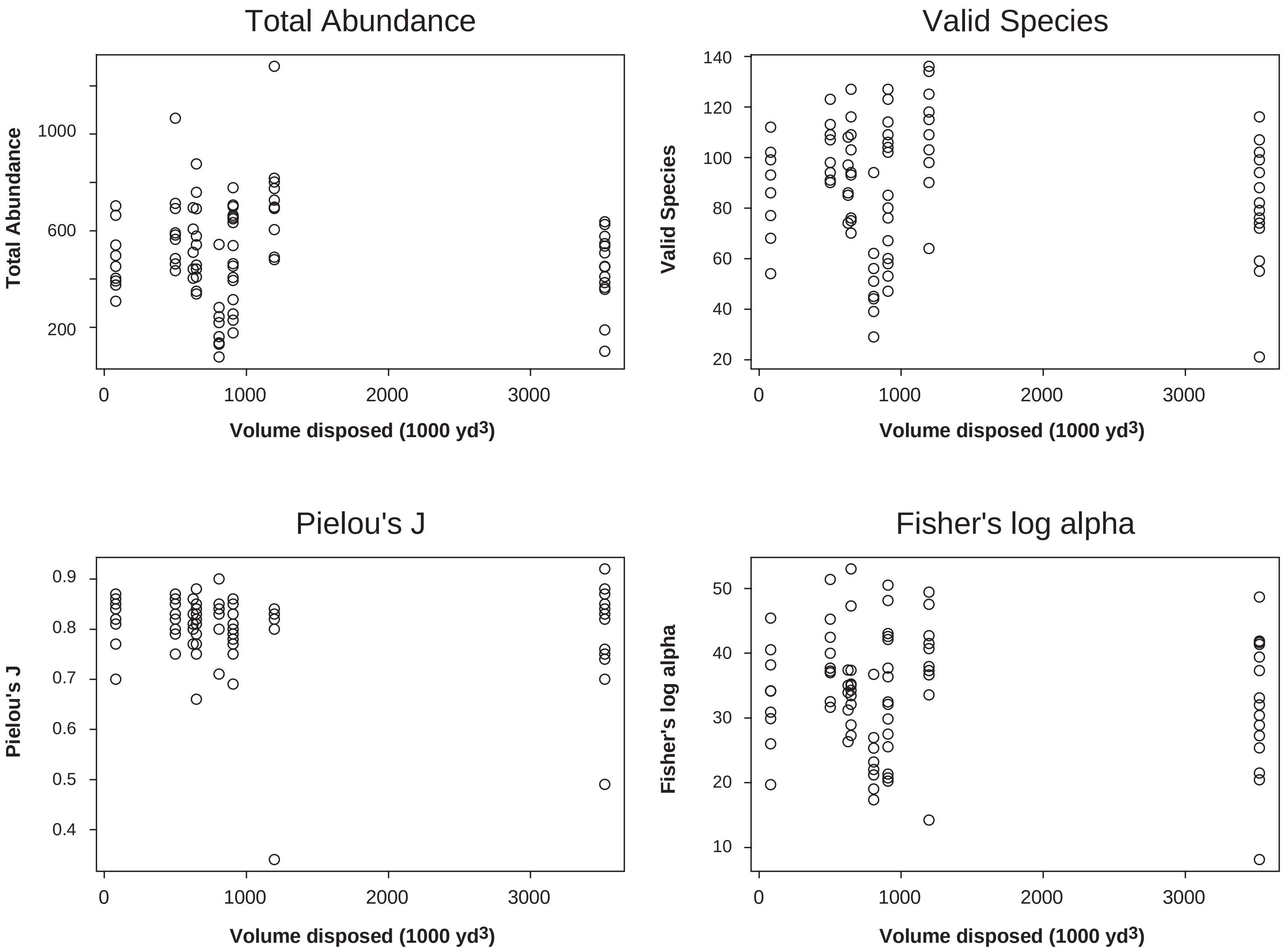


Figure 15: Diversity data from Table 4-2 (ENSR 2005). Diversity values for each station are shown on y-axis, plotted against the estimated volume disposed since last sampling (thousands of cubic yards). Only stations with dredged material present are shown; pattern is the same when dredged material absent stations are included.

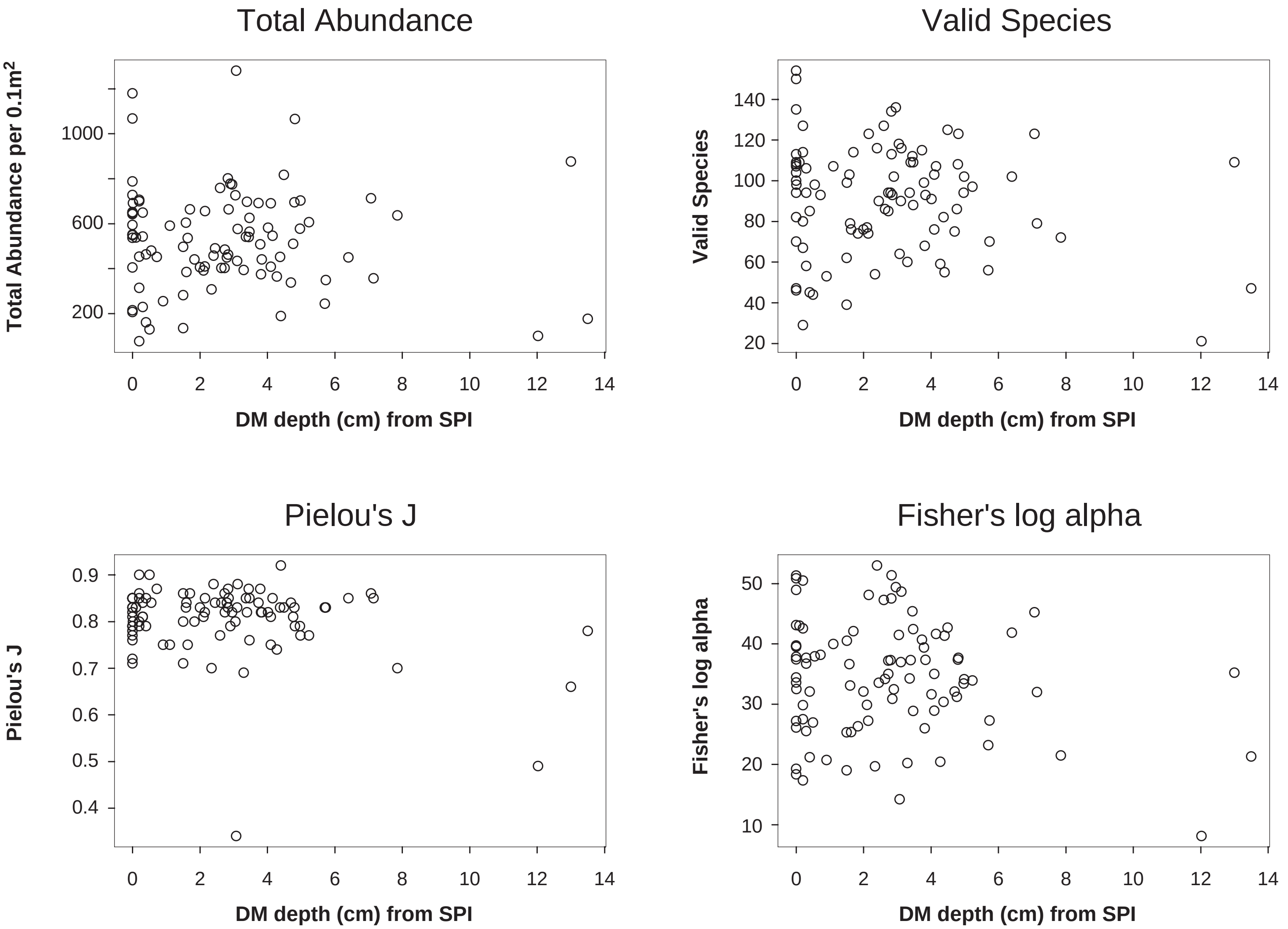


Figure 16: Benthic community metrics (from Table 4-2, ENSR 2005) plotted against actual dredged material depth (cm) measured in sediment profile images.

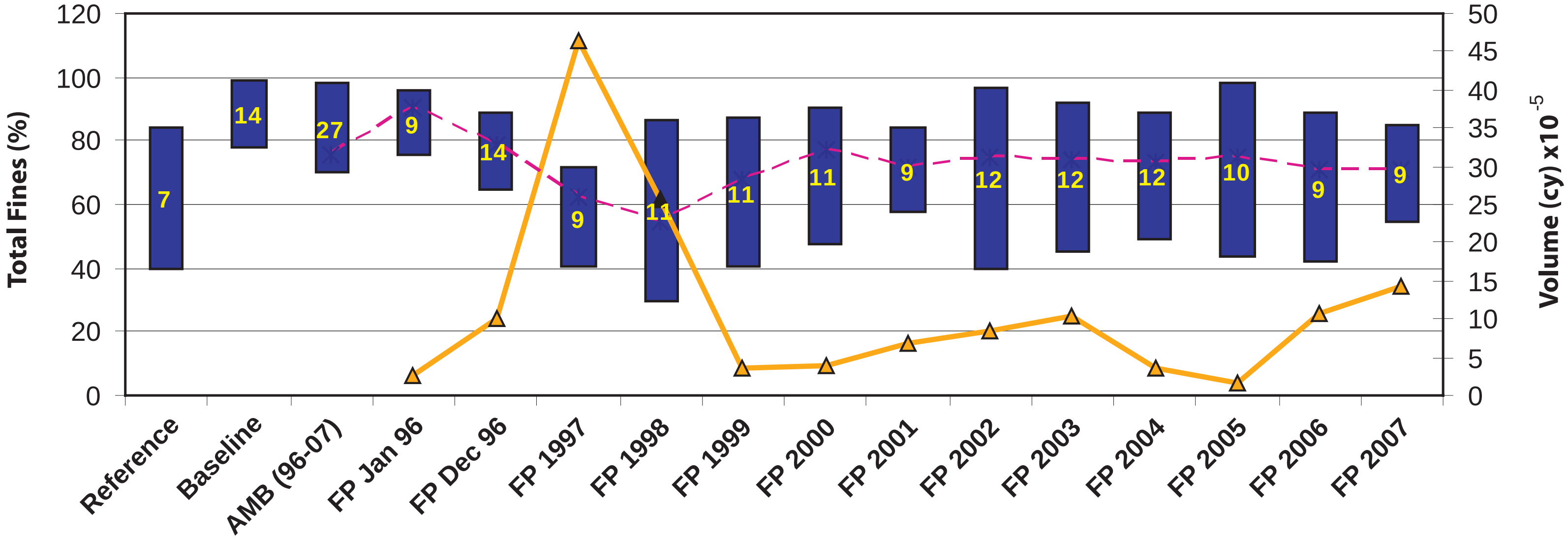


Figure 17: Range (minimum to maximum, columns) and average (dashed line) concentration of total fine-grained sediment (silt and clay) in samples collected from SF-DODS and the SF-DODS reference area relative to volume of dredged material disposed at the site during that year (line), in cubic yards ($x10^{-5}$). Baseline samples collected in 1990-91. Ambient samples grouped for display; dredged material footprint (FP) samples shown for each survey year, with number of samples shown in the center of the column.

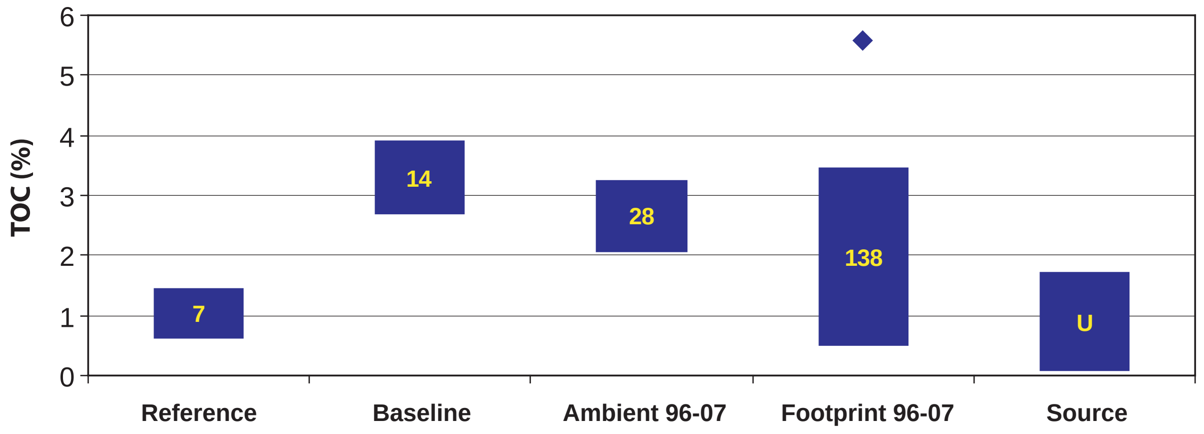


Figure 18: Range (minimum to maximum) of total organic carbon (TOC) in samples collected from SFDODS, the reference area, and from dredged material source areas (columns). Baseline samples collected in 1990-91. Ambient stations are those with no measurable dredged material. Outlier point shown separately for Footprint category. Source data summarized as reported over 1994-2006 (Appendix Table B2). Number of samples shown in the center of the column; U=unknown number of source samples.

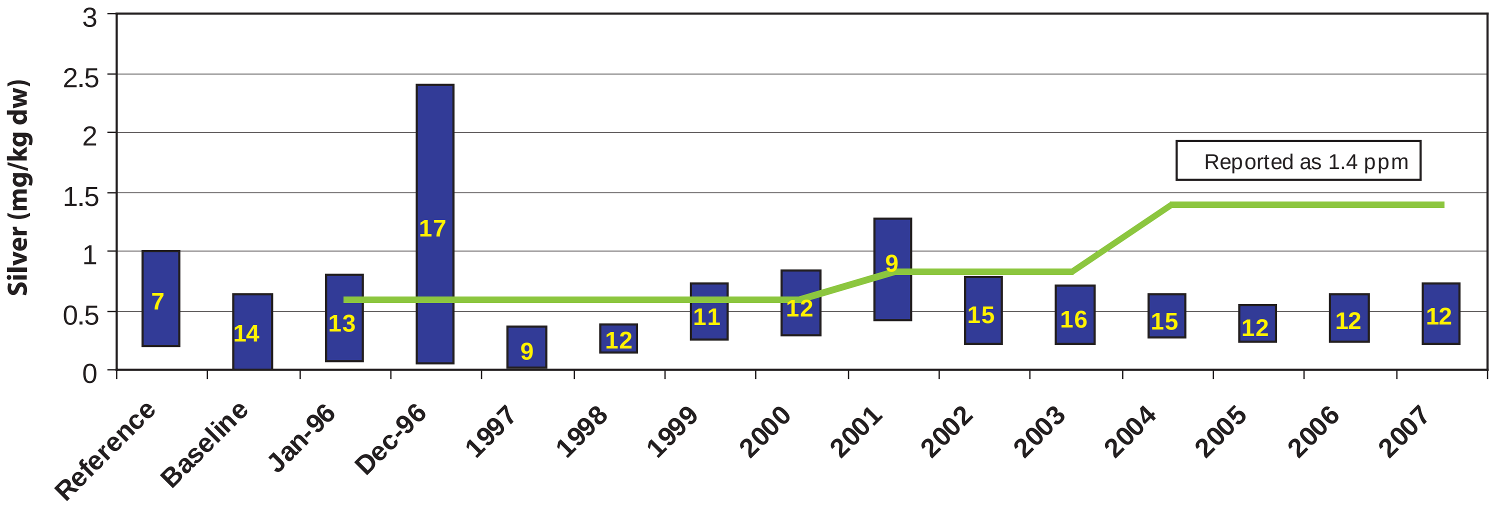


Figure 19: Range (minimum to maximum) concentration of silver in samples collected from SF-DODS and the reference area (columns). Baseline samples collected in 1990-91. Green line showing maximum silver value reported from dredged material source areas through 2000 (0.6 ppm), for 2001-2003 (0.84 ppm), and from 2004 to present (reported as 1.4 ppm; SAIC et al. 2005). Number of samples shown in the center of the column.

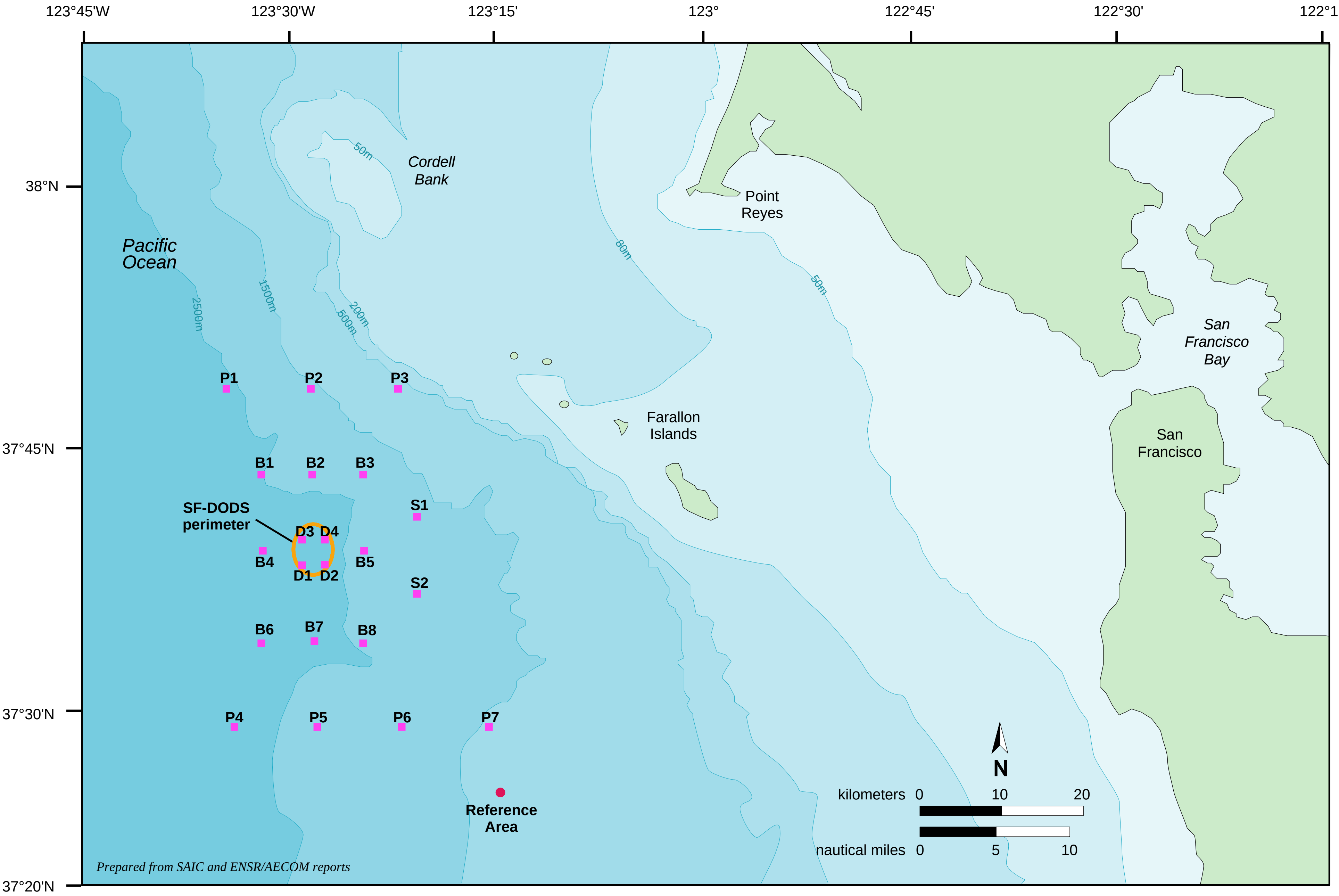


Figure 20: Location of the 21 stations used for pelagic fish monitoring surveys in the vicinity of SF-DODS. D stations are disposal site stations; B stations are "buffer area" stations; and P stations are "peripheral area" stations.

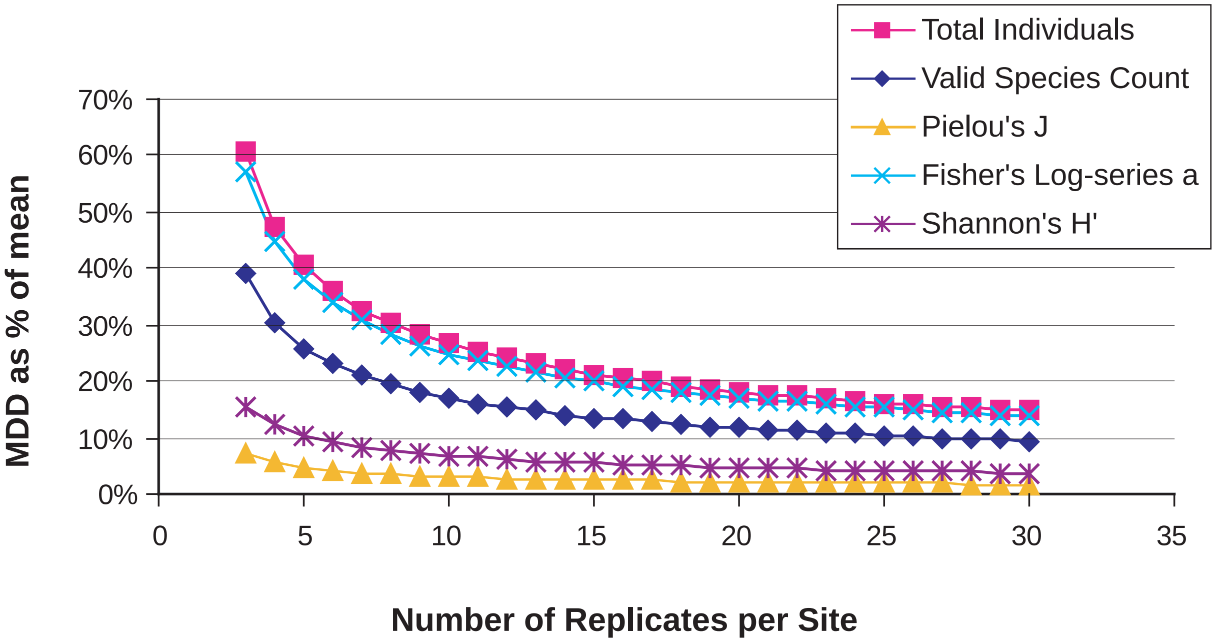


Figure 21: Power Analysis Results: relationship between the number of replicates per site vs. the Mean Detection Difference (MDD) as a percentage of the mean, given a type I error rate (alpha) = 0.05 and 80% power.

APPENDIX

Appendix Table 1

Chemical Group	Chemical	Survey Date	SF-DODS Ambient (1996-2008)			SF-DODS Footprint (1996-2008)		
			N	Range	Avg ± 1SD	N	Range	Avg ± 1SD
Conventionals	TOC	1996-Jan	4	2.4 - 3.2	2.7 ± 0.3	9	1.6 - 2.8	2.4 ± 0.5
		1996-Dec	3	2.1 - 2.3	2.2 ± 0.1	14	0.87 - 2.3	1.8 ± 0.4
		1997		-	-	9	1.4 - 2.6	2.1 ± 0.5
		1998	1	2.1	2.1	11	0.51 - 2.9	1.6 ± 0.7
		1999		-	-	11	0.67 - 2.7	1.9 ± 0.7
		2000	1	2.4	2.4	11	1 - 3	2.1 ± 0.6
		2001		-	-	9	1.5 - 3.1	2.2 ± 0.5
		2002	3	2.9 - 3.1	3 ± 0.1	12	0.9 - 3	2.1 ± 0.7
		2003	4	2.8 - 3	2.9 ± 0.08	12	0.66 - 5.6	2.3 ± 1.3
		2004	4	2.8 - 3	2.9 ± 0.1	12	1.2 - 3.4	2.2 ± 0.6
		2005	2	2.8 - 3.1	2.9 ± 0.2	10	1.2 - 2.6	1.9 ± 0.5
		2006	3	2.9 - 3.2	3 ± 0.2	9	1 - 2.8	2 ± 0.6
		2007	3	2.8 - 3.2	3 ± 0.2	9	0.99 - 2.8	1.8 ± 0.6
		2008	0	-	-	2	1.2 - 2	1.6 ± 0.5
	Total Solids	1996-Jan	4	30.7 - 32.1	31.5 ± 0.6	9	17 - 52	35 ± 11.8
		1996-Dec	3	29.1 - 34.1	-	14	32 - 47	37 ± 4
		1997		-	-	9	34 - 52	43 ± 6.8
		1998	1	35.1	35.1	11	33 - 65	48 ± 9.2
		1999		-	-	11	20 - 55	39 ± 9.8
		2000	1	37.1	37.1	11	30 - 53	40 ± 7.2
		2001		-	-	9	28 - 50	39 ± 6.5
		2002	3	28 - 32.9	30 ± 2	12	33 - 55	41 ± 7.4
		2003	4	28.8 - 32.3	30.3 ± 1.5	12	31 - 52	38 ± 6.4
		2004	4	29.4 - 31.8	30.6 ± 1.1	12	32 - 52	39 ± 6
		2005	2	30.3 - 31.4	30.8 ± 0.8	10	32 - 53	42 ± 5.8
		2006	3	31 - 33	32 ± 1	9	33 - 55	41 ± 7.3
		2007	3	31 - 32	31.8	9	35 - 50	42 ± 5
		2008		-	-	2	41 - 46	43 ± 4
	Fines	1996-Jan	4	94 - 97	95.2	9	75 - 96	90 ± 7
		1996-Dec	3	85 - 90	87 ± 3	14	64 - 89	79 ± 6.9
		1997		-	-	9	40 - 72	63 ± 12
		1998	1	70	69.8	11	29 - 87	54 ± 19
		1999		-	-	11	41 - 87	68 ± 15.3
		2000	1	84	83.5	11	48 - 90	77 ± 14
		2001		-	-	9	58 - 84	72 ± 9.3
		2002	3	95 - 97	96 ± 1	12	40 - 97	75.1 ± 15.4
		2003	4	89 - 98	94 ± 4	12	45 - 92	74.3 ± 13.3
		2004	4	92 - 98	95 ± 3	12	49 - 89	73.3 ± 12.1
		2005	2	91 - 94	92.7	10	43 - 98	74.6 ± 15
		2006	3	88 - 98	94 ± 5	9	42 - 89	70.8 ± 13.5
		2007	2	72 - 91	81.4	9	55 - 85	71.3 ± 8.3
		2008		-	-	2	71 - 85	77.9 ± 10.4
Metals	Arsenic	1996-Jan	4	3.1 - 5.4	4.4 ± 1	9	0.7 - 7.5	3.8 ± 2.6
		1996-Dec	3	2.9 - 5.3	4.1 ± 1.2	14	2 - 7.5	5.2 ± 1.3
		1997		-	-	9	1.7 - 3.3	2.8 ± 0.5
		1998	1	3.1	3.1	11	2.1 - 4.1	3 ± 0.6
		1999		-	-	11	2.6 - 4.1	3.4 ± 0.5
		2000	1	3.3	3.3	11	2.4 - 4.8	3.3 ± 0.7

APPENDIX TABLE 1

Chemical Group	Chemical	Survey Date	SF-DODS Ambient (1996-2008)			SF-DODS Footprint (1996-2008)		
			N	Range	Avg ± 1SD	N	Range	Avg ± 1SD
		2001		-	-	9	3.2 - 4.6	3.83 ± 0.45
		2002	3	3.2 - 3.9	3.5 ± 0.36	12	2.4 - 5.7	3.27 ± 0.83
		2003	4	2.9 - 3.4	3.1 ± 0.22	12	2.5 - 7.6	3.55 ± 1.45
		2004	3	3.4 - 4.3	3.8	12	2.5 - 7.2	3.44 ± 1.24
		2005	2	3 - 3.3	3.1 ± 0.23	10	2.3 - 6.1	3.48 ± 1
		2006	3	3.5 - 4.4	4	9	2.9 - 8.3	3.97 ± 1.66
		2007	3	3.1 - 4.1	3.6 ± 0.5	9	2.6 - 6.8	3.75 ± 1.39
		2008		-	-	2	2.8 - 5.9	4.37 ± 2.21
	Cadmium	1996-Jan	4	0.3 - 0.37	0.32 ± 0	9	0.14 - 0.52	0.31 ± 0.1
		1996-Dec	3	0.1 - 0.18	0.14 ± 0.04	14	0.11 - 0.19	0.14 ± 0.02
		1997		-	-	9	0.12 - 0.28	0.19 ± 0.05
		1998	1	0.19	0.2	11	0.09 - 0.27	0.15 ± 0.06
		1999		-	-	11	0.16 - 0.52	0.3 ± 0.1
Metals, cont.	Cadmium	2000	1	0.41	0.4	11	0.16 - 0.41	0 ± 0
		2001		-	-	9	0.26 - 0.42	0 ± 0
		2002	3	0.29 - 0.43	0.34 ± 0.08	12	0.12 - 0.53	0 ± 0.1
		2003	4	0.23 - 0.48	0.33 ± 0.11	12	0.12 - 0.42	0 ± 0.1
		2004	3	0.3 - 0.37	0.33 ± 0.03	12	0.18 - 0.33	0 ± 0.1
		2005	2	0.16 - 0.2	0.18 ± 0.03	10	0.12 - 0.21	0 ± 0
		2006	3	0.29 - 0.53	0.37 ± 0.14	9	0.14 - 0.29	0 ± 0
		2007	3	0.28 - 0.38	0.32 ± 0.06	9	0.15 - 0.42	0 ± 0.1
		2008		-	-	2	0.24 - 0.29	0 ± 0
	Chromium	1996-Jan	4	85 - 90	87 ± 2	9	40 - 92	68 ± 20
		1996-Dec	3	66 - 75	72 ± 5	14	61 - 120	79 ± 15
		1997		-	-	9	60 - 81	69 ± 7.9
		1998	1	52	52.4	11	31 - 56	42 ± 7.5
		1999		-	-	11	37 - 60	47 ± 7
		2000	1	60	59.6	11	49 - 71	57 ± 6.9
		2001		-	-	9	38 - 52	43 ± 4.6
		2002	3	55 - 58	56 ± 2	12	32 - 56	45 ± 6.4
		2003	4	64 - 71	67 ± 3	12	43 - 74	61 ± 8.6
		2004	3	79 - 85	81 ± 3	12	51 - 89	74 ± 10.3
		2005	2	40 - 54	47 ± 10	10	33 - 73	48 ± 15.9
		2006	3	83 - 86	85 ± 1	9	52 - 81	69 ± 8.6
		2007	3	72 - 77	74 ± 3	9	50 - 73	63 ± 7.8
		2008		-	-	2	46 - 55	50 ± 6.3
	Copper	1996-Jan	4	50 - 57	55 ± 3	9	36 - 53	46 ± 6.2
		1996-Dec	3	42 - 47	44 ± 3	14	29 - 62	42 ± 9.3
		1997		-	-	9	7.3 - 21	15 ± 4.4
		1998	1	34	34.4	11	16 - 37	23 ± 7.5
		1999		-	-	11	21 - 45	34 ± 8
		2000	1	28	28.3	11	20 - 47	32.3 ± 8.1
		2001		-	-	9	27 - 55	37 ± 8.4
		2002	3	30 - 52	42 ± 11.1	12	18 - 44	33.1 ± 7.6
		2003	4	34 - 50	41 ± 7.1	12	20 - 47	34.3 ± 7.3
		2004	3	41 - 54	47 ± 6.7	12	22 - 45	33.9 ± 6.6
		2005	2	37 - 39	38 ± 1.8	10	20 - 41	29.1 ± 5.4
		2006	3	42 - 64	54 ± 11	9	24 - 52	40.4 ± 8.8
		2007	3	28 - 45	37 ± 8.3	9	21 - 37	29 ± 4.6
		2008		-	-	2	29 - 30	29.4 ± 0.4
	Lead	1996-Jan	4	20 - 25	23 ± 2.1	9	16 - 29	22.8 ± 3.8

APPENDIX TABLE 1

Chemical Group	Chemical	Survey Date	SF-DODS Ambient (1996-2008)			SF-DODS Footprint (1996-2008)		
			N	Range	Avg ± 1SD	N	Range	Avg ± 1SD
		1996-Dec	3	8 - 16	11.1 ± 4.3	14	6.6 - 35	21 ± 8.7
		1997		-	-	9	3.5 - 8	5.8 ± 1.5
		1998	1	6.6	6.6	11	4.4 - 10	6.9 ± 1.77
		1999		-	-	11	5.3 - 7.7	6.5 ± 0.7
		2000	1	5.2	5.2	11	5.5 - 7.7	6.39 ± 0.62
		2001		-	-	9	6.4 - 10	7.4 ± 1.22668
		2002	3	7.7 - 8.4	8 ± 0.33	12	5.4 - 21	9.1 ± 5
		2003	4	6.9 - 7.4	7.1 ± 0.18	12	5.1 - 21	7.69 ± 4.2
		2004	3	7.5 - 8.9	8.1 ± 0.74	12	5.9 - 23	8.41 ± 4.56
		2005	2	6.5 - 7.3	6.9 ± 0.55	10	5.4 - 19	7.63 ± 4.02
		2006	3	7.4 - 8.4	7.9 ± 0.465	9	6.2 - 20	8.34 ± 4.33
		2007	3	6.6 - 7.4	7.1 ± 0.42	9	4.8 - 20	9.17 ± 5.33
		2008		-	-	2	7.8 - 21	14.23 ± 9.07
	Mercury	1996-Jan	4	0.03 - 0.04	0.03 ± 0	9	0.022 - 0.076	0.04 ± 0.02
		1996-Dec	3	0.03 - 0.08	0.05 ± 0.03	14	0.024 - 0.25	0.09 ± 0.07
		1997		-	-	9	0.02 - 0.061	0.03 ± 0.01
		1998	1	0.11	0.1	11	0.06 - 0.24	0.11 ± 0.06
		1999		-	-	11	0.1 - 0.1	0.1 ± 0
		2000	1	0.02	0	11	0.02 - 0.06	0.03 ± 0.01
Metals, cont.	Mercury	2001		-	-	9	0.09 - 0.12	0.1 ± 0.01
		2002	3	0.1 - 0.12	0.11 ± 0.01	12	0.07 - 0.16	0.1 ± 0.02
		2003	4	0.09 - 0.13	0.11 ± 0.02	12	0.08 - 0.21	0.11 ± 0.04
		2004	3	0.12 - 0.12	0.12 ± 0	12	0.078 - 0.2	0.11 ± 0.03
		2005	2	0.13 - 0.16	0.14 ± 0.02	10	0.096 - 0.23	0.13 ± 0.04
		2006	3	0.13 - 0.16	0.15 ± 0.02	9	0.087 - 0.22	0.13 ± 0.04
		2007	3	0.1 - 0.13	0.11 ± 0.02	9	0.08 - 0.21	0.12 ± 0.05
		2008		-	-	2	0.12 - 0.26	0.19 ± 0.1
	Nickel	1996-Jan	4	69 - 72	70 ± 1.5	9	56 - 80	66.8 ± 6.5
		1996-Dec	3	67 - 74	71 ± 3.6	14	62 - 97	72 ± 8.4
		1997		-	-	9	51 - 78	67 ± 9.06
		1998	1	54	54	11	4.8 - 58	39.1 ± 14.3
		1999		-	-	11	42 - 72	57.3 ± 8.5
		2000	1	59	59	11	45 - 84	61.7 ± 11.3
		2001		-	-	9	55 - 77	61 ± 7.3
		2002	3	64 - 70	68 ± 3.2	12	38 - 67	56.1 ± 8
		2003	4	63 - 67	65 ± 2.3	12	42 - 70	59.2 ± 8
		2004	3	69 - 72	70 ± 1.7	12	43 - 67	58.3 ± 7
		2005	2	55 - 60	57 ± 3.5	10	40 - 63	51.6 ± 6.7
		2006	3	83 - 86	84 ± 1.2	9	50 - 76	69 ± 8.7
		2007	3	60 - 64	62 ± 1.9	9	42 - 58	51.8 ± 5.2
		2008		-	-	2	45 - 48	46.18 ± 2.09
	Selenium	1996-Jan	4	3.7 - 4.4	4 ± 0.3	9	1.4 - 4	2.8 ± 0.9
		1996-Dec	3	1.8 - 2.3	2 ± 0.3	14	0.14 - 2.4	1.09 ± 0.82
		1997		-	-	9	0.17 - 0.27	0.22 ± 0.03
		1998	1	3.2	3.2	9	0.6 - 3.2	1.98 ± 0.92
		1999		-	-	11	1 - 5	3.55 ± 1.37

APPENDIX TABLE 1

Chemical Group	Chemical	Survey Date	SF-DODS Ambient (1996-2008)			SF-DODS Footprint (1996-2008)		
			N	Range	Avg ± 1SD	N	Range	Avg ± 1SD
		2000	1	3.4	3.4	11	1.6 - 4.4	2.99 ± 0.95
		2001		-	-	9	2.7 - 2.7	2.65 ± 0
		2002	3	3 - 3.8	3.5 ± 0.44	12	0.3 - 4	2.64 ± 1.06
		2003	4	2.7 - 3.2	3 ± 0.21	12	0.5 - 3.1	2.17 ± 0.77
		2004	3	4.4 - 4.6	4.5 ± 0.12	12	0.8 - 4.3	2.95 ± 1.03
		2005	2	2.3 - 2.6	2.4 ± 0.18	10	0.2 - 2.4	1.71 ± 0.69
		2006	3	3.5 - 3.9	3.6 ± 0.23	9	0.4 - 3.2	2.24 ± 0.98
		2007	3	3.4 - 3.7	3.5 ± 0.2	9	1.1 - 3.1	2 ± 1
		2008		-	-	2	0.7 - 2.6	2 ± 1
	Silver	1996-Jan	4	0.2 - 0.4	0.33 ± 0.1	9	0.08 - 0.8	0 ± 0
		1996-Dec	3	0.68 - 1.2	0.93 ± 0.26	14	0.06 - 2.4	1 ± 1
		1997		-	-	9	0.015 - 0.37	0 ± 0
		1998	1	0.35	0.3	11	0.14 - 0.38	0 ± 0
		1999		-	-	11	0.25 - 0.73	0 ± 0
		2000	1	0.53	0.5	11	0.3 - 0.83	0 ± 0
		2001		-	-	9	0.42 - 1.3	1 ± 0.3
		2002	3	0.5 - 0.61	0.56 ± 0.05	12	0.22 - 0.78	0 ± 0
		2003	4	0.45 - 0.62	0.54 ± 0.07	12	0.22 - 0.71	0 ± 0.1
		2004	3	0.47 - 0.64	0.58 ± 0.09	12	0.28 - 0.62	0 ± 0
		2005	2	0.43 - 0.49	0.46 ± 0.04	10	0.24 - 0.54	0 ± 0.1
		2006	3	0.49 - 0.62	-	9	0.24 - 0.63	0 ± 0.1
		2007	3	0.46 - 0.54	0.51 ± 0.04	9	0.21 - 0.73	0 ± 0.2
		2008		-	-	2	0.3 - 0.52	0 ± 0.2
	Zinc	1996-Jan	4	94 - 100	97 ± 2.6	9	68 - 100	91.6 ± 9.8
		1996-Dec	3	92 - 100	97 ± 4	14	76 - 120	94 ± 10.9
		1997		-	-	9	69 - 110	92 ± 13.8
		1998	1	71	71.2	11	36 - 75	52 ± 13.6
		1999		-	-	11	46 - 96	73 ± 14.9
		2000	1	72	71.6	11	49 - 85	69 ± 12
		2001		-	-	9	63 - 98	74 ± 12.4
Metals, cont.	Zinc	2002	3	85 - 104	96 ± 10	12	42 - 135	80 ± 22.2
		2003	4	75 - 85	79 ± 5	12	43 - 86	69 ± 12
		2004	3	85 - 95	89 ± 5	12	47 - 83	70 ± 11
		2005	2	68 - 70	69 ± 2	10	41 - 71	59 ± 8
		2006	3	102 - 113	107 ± 6	9	55 - 96	84 ± 14
		2007	3	67 - 76	71 ± 4	9	43 - 67	59 ± 7
		2008		-	-	2	52 - 60	56 ± 6
Organics	Diesel Range Organics	2001		-	-	9	34 - 34	34 ± 0
		2002	3	12 - 14	13	12	7.5 - 24	14 ± 6
		2003	4	21 - 25	-	12	13 - 23	18 ± 3
		2004	3	12 - 13	12 ± 1	12	7 - 12	9 ± 1
		2005	2	19 - 24	22 ± 4	10	7.9 - 35	16 ± 8
		2006	3	11 - 19	15 ± 4	9	7.1 - 28	14 ± 6
		2007	3	13 - 18	16 ± 3	9	8.8 - 22	13.1 ± 4.8
		2008		-	-	2	6 - 17	11.5 ± 7.8
	TPH	1996-Jan	4	12 - 35	25 ± 10	9	9 - 25	15.3 ± 5.6
		1996-Dec	3	17 - 27	22 ± 5	14	13 - 50	27 ± 10
		1997		-	-	9	24 - 42	31 ± 5

APPENDIX TABLE 1

Chemical Group	Chemical	Survey Date	SF-DODS Ambient (1996-2008)			SF-DODS Footprint (1996-2008)		
			N	Range	Avg ± 1SD	N	Range	Avg ± 1SD
		1998	1	25	25	11	25 - 25	25 ± 0
		1999		-	-	11	13 - 13	13 ± 0
		2000	1	10	10	11	10 - 65	31 ± 16.1
PAHs	Total HPAH	1996-Jan	4	164 - 188	-	9	124 - 176	155 ± 19
		1996-Dec	3	168 - 192	183 ± 13	14	136 - 1119	266 ± 263
		1997		-	-	9	104 - 172	132 ± 21.6
		1998	1	109	109	11	78 - 645	196 ± 169
		1999		-	-	11	34 - 224	113 ± 52
		2000	1	39	39	11	21 - 139	71 ± 29
		2001		-	-	9	75 - 415	137 ± 108
		2002	3	68 - 118	101 ± 29	12	39 - 314	99 ± 73
		2003	4	20 - 41	31 ± 10	12	14 - 231	49 ± 61
		2005	2	33 - 34	34 ± 1	10	27 - 493	90 ± 143
		2006	3	45 - 79	60 ± 17	9	29 - 2749	362 ± 896
		2007	3	28 - 38	31 ± 6	9	19 - 508	149 ± 160
	Total LPAH	1996-Jan	4	123 - 141	133 ± 8	9	78 - 218	132 ± 40
		1996-Dec	3	126 - 144	137 ± 10	14	102 - 239	125 ± 34
		1997		-	-	9	78 - 129	99 ± 16
		1998	1	40	40	11	35 - 77	45 ± 11
		1999		-	-	11	19 - 50	32 ± 8
		2000	1	23	23	11	20 - 28	24 ± 2
		2001		-	-	9	49 - 104	60 ± 17
		2002	3	27 - 58	39 ± 16	12	17 - 40	25 ± 6
		2003	4	8.9 - 12	10.7 ± 1.7	12	5.5 - 37	12 ± 9
		2005	2	29 - 29	29 ± 0	10	20 - 86	29 ± 20.1
		2006	3	23 - 26	24 ± 2	9	15 - 1298	168 ± 423.9
		2007	3	25 - 27	26 ± 2	9	17 - 87	35 ± 21.9
	Total PAH	1996-Jan	4	287 - 329	310 ± 19	9	217 - 390	287 ± 51
		1996-Dec	3	294 - 336	320 ± 23	14	238 - 1358	391 ± 293.9
		1997		-	-	9	182 - 301	230 ± 37.8
		1998	1	149	149	11	118 - 722	241 ± 178.5
		1999		-	-	11	53 - 259	145 ± 57.1
		2000	1	62	62	11	41 - 164	95 ± 30.9
		2001		-	-	9	129 - 519	197 ± 124.3
		2002	3	94 - 176	141 ± 41.91	12	63 - 353	124.25 ± 77.95
		2003	4	30 - 53	42 ± 11.43	12	20 - 268	60.77 ± 69.27
PAHs, cont.	Total PAH	2005	2	62 - 63	63 ± 0.53	10	47 - 579	119.99 ± 162.74
		2006	3	71 - 101	84 ± 15.69	9	44 - 4047	530.7 ± 1319.4
		2007	3	52 - 66	57 ± 7.54	9	40 - 594	183.71 ± 181.42
PCBs	Total PCB	1996-Jan	4	101 - 116	110 ± 6.76	9	65 - 110	93.11 ± 15.56
		1996-Dec	3	106 - 121	115 ± 8.39	14	76 - 139	99 ± 15.1
		1997		-	-	9	66 - 110	83 ± 14.1
		1998	1	70	70	11	70 - 70	70 ± 0
		1999		-	-	11	50 - 50	50 ± 0
		2000	1	60	60	11	60 - 60	60 ± 0
		2001		-	-	9	144 - 144	143.5 ± 0

APPENDIX TABLE 1

Chemical Group	Chemical	Survey Date	SF-DODS Ambient (1996-2008)			SF-DODS Footprint (1996-2008)		
			N	Range	Avg ± 1SD	N	Range	Avg ± 1SD
		2002	3	9.5 - 16	11.8 ± 3.2328	12	5.6 - 32	11.08 ± 6.92
		2003	4	20 - 22	21 ± 1.11	12	12 - 20	17.16 ± 2.58
		2004	3	20 - 24	21 ± 2.22	12	12 - 34	18.85 ± 5.44
		2005	2	52 - 56	54 ± 2.47	10	40 - 52	42.35 ± 4.23
		2006	3	52 - 52	52 ± 0.29	9	30 - 52	41.2 ± 7.3
		2007	3	52 - 52	52 ± 0.29	9	40 - 48	42.62 ± 3.73
Pesticides	Aldrin	1996-Jan	4	0.6 - 0.7	0.66 ± 0.05	9	0.4 - 0.65	0.56 ± 0.09
		1996-Dec	3	0.65 - 0.75	0.7 ± 0.05	14	0.46 - 0.7	0.6 ± 0.1
		1997		-	-	9	0.4 - 0.65	0.5 ± 0.08
		1998	1	2	2	11	2 - 2	2 ± 0
		1999		-	-	11	1 - 1	1 ± 0
		2000	1	1	1	11	1 - 1	1 ± 0
		2001		-	-	9	1.5 - 1.5	1.45 ± 0
		2002	3	1.9 - 2.8	2.5 ± 0.5196	12	0.72 - 3.6	1.99 ± 0.94
		2003	4	0.39 - 0.44	0.41 ± 0	12	0.24 - 0.4	0.3 ± 0.1
		2004	3	0.41 - 0.6	0.48 ± 0.1	12	0.24 - 0.85	0.4 ± 0.2
		2005	2	0.65 - 0.7	0.67 ± 0	10	0.5 - 0.65	0.5 ± 0.1
		2006	3	0.65 - 0.65	0.65 ± 0	9	0.37 - 0.65	0.5 ± 0.1
		2007	3	0.65 - 0.65	0.65 ± 0	9	0.5 - 0.6	0.5 ± 0
		2008		-	-	2	0.09 - 0.095	0.1 ± 0
	Dieldrin	1996-Jan	4	0.8 - 0.95	0.88 ± 0.1	9	0.5 - 0.85	0.7 ± 0.1
		1996-Dec	3	0.85 - 0.95	0.92 ± 0.1	14	0.7 - 2.4	1 ± 0.5
		1997		-	-	9	0.55 - 0.85	0.7 ± 0.1
		1998	1	2	2	11	2 - 2	2 ± 0
		1999		-	-	11	1 - 1	1 ± 0
		2000	1	1	1	11	1 - 1	1 ± 0
		2001		-	-	9	1.8 - 1.8	1.8 ± 0
		2002	3	0.47 - 0.55	0.52 ± 0	12	0.28 - 2	0.6 ± 0.6
		2003	4	0.13 - 0.15	0.14 ± 0	12	0.08 - 0.91	0.3 ± 0.3
		2004	3	1.3 - 1.5	1.4 ± 0.1	12	0.15 - 1.2	0.7 ± 0.4
		2005	2	0.65 - 0.7	0.67 ± 0	10	0.5 - 0.65	0.5 ± 0.1
		2006	3	0.65 - 0.65	0.65 ± 0	9	0.37 - 0.65	0.5 ± 0.1
		2007	3	0.65 - 0.65	0.65 ± 0	9	0.5 - 0.6	0.5 ± 0
		2008		-	-	2	0.16 - 0.18	0.2 ± 0
	Total BHC	1996-Jan	4	2.2 - 2.6	2.4 ± 0.2	9	1.2 - 2.4	2 ± 0.4
		1996-Dec	3	2.4 - 2.7	2.5 ± 0.2	14	1.7 - 2.6	2.1 ± 0.2
		1997		-	-	9	1.5 - 2.4	1.9 ± 0.3
		1998	1	6	6	11	6 - 6	6 ± 0
		1999		-	-	11	3 - 3	3 ± 0
		2000	1	3	3	11	3 - 3	3 ± 0
		2001		-	-	9	5.4 - 17	7.2 ± 3.7
		2002	3	6.4 - 22	12.9 ± 8.3	12	2.7 - 14	7.7 ± 4.8
		2003	4	1.7 - 4.2	2.8 ± 1.1	12	0.46 - 8.1	2.1 ± 2
		2004	3	0.74 - 11	4.56 ± 5.4	12	0.38 - 5.1	2.4 ± 1.4
		2005	2	2.1 - 3.3	2.7 ± 0.8	10	1.5 - 3.4	1.92 ± 0.64
Pesticides, cont.	Total BHC	2006	3	2 - 2.6	2.2 ± 0.4	9	1.1 - 4.4	2.16 ± 1.11
		2007	3	1.6 - 2	1.8 ± 0.2	9	1.3 - 4.1	1.7 ± 0.9
	Total DDTs	1996-Jan	4	3.9 - 4.6	4.2 ± 0.3	9	2.5 - 5.2	3.7 ± 0.8

APPENDIX TABLE 1

Chemical Group	Chemical	Survey Date	SF-DODS Ambient (1996-2008)			SF-DODS Footprint (1996-2008)		
			N	Range	Avg ± 1SD	N	Range	Avg ± 1SD
		1996-Dec	3	6.5 - 7.6	7.1 ± 0.6	14	5.1 - 8.7	6.4 ± 0.9
		1997		-	-	9	2.55 - 5.21	3.4 ± 0.8
		1998	1	6	6	11	6 - 9	6.5 ± 1.2
		1999		-	-	11	3 - 3	3 ± 0
		2000	1	3	3	11	3 - 5.4	3.6 ± 0.7
		2001		-	-	9	5.4 - 5.4	5.4 ± 0
		2002	3	4.33 - 7.01	5.99 ± 1.45	12	2.33 - 11.5	5.1 ± 2.4
		2003	4	1.45 - 1.91	1.65 ± 0.2	12	1.04 - 3.33	1.8 ± 0.8
		2004	3	3.63 - 23.75	10.92 ± 11.14	12	2.73 - 15.31	7 ± 4.1
		2005	2	3.35 - 3.8	3.58 ± 0.32	10	1.5 - 4.2	2.8 ± 0.9
		2006	3	2.5 - 4.59	3.4 ± 1.07	9	1.78 - 4.6	3.1 ± 1
		2007	3	1.77 - 2.09	1.94 ± 0.16	9	1.4 - 2.9	1.7 ± 0.5
Organotins	Tri-n-butyltin	1999		-	-	11	0.5 - 38	4 ± 11.3
		2000	1	2	2	11	1.5 - 1.5	1.5 ± 0
		2001		-	-	9	1.6 - 1.8	1.8 ± 0.1
		2002	3	1.55 - 1.8	1.67 ± 0.13	11	1.1 - 4.2	1.6 ± 0.9
		2003	4	0.6 - 0.65	0.6 ± 0.02	12	0.36 - 1.9	0.7 ± 0.4
		2004	3	0.26 - 0.28	0.26 ± 0.01	12	0.16 - 3.2	0.6 ± 0.9
		2005	2	1.6 - 1.65	1.6 ± 0.04	10	0.95 - 1.6	1.2 ± 0.2
		2006	3	1.55 - 1.65	1.61 ± 0.05	9	0.81 - 1.8	1.3 ± 0.3
		2007	3	1.55 - 1.6	1.57 ± 0.03	9	0.95 - 3.9	1.6 ± 0.9
		2008		-	-	2	0.37 - 3.25	1.8 ± 2

Appendix Table 2. Summary of range of sediment chemistry measured at SF-DODS and source areas.

Chemical	SF-DODS Baseline (1990-91)	SF-DODS Monitoring Data (1996-2008)			Dredged Material Characterization Data (1994-2006)			SF-DODS Reference
	Range	N	Min	Max	Min	Max	Max Source[1]	Range
Conventionals								
Total Solids (%)	-	170	17.25	65.2	32	82.9	POA	33-59
Percent Fines	78-99	169	29.3	98.44	1.28	99.3	RIH	40-84
TOC (%)	2.7-3.9	170	0.51	5.59	0.08	1.71	RIH	0.63-1.45
Metals (mg/kg dw)								
Arsenic	nd-5.2	169	0.7	8.3	3.18	14.7	RIH	2.2-5.33
Cadmium	nd-0.38	169	0.09	0.53	0.05	1.1	OIH	0.3-0.6
Chromium	91-167	169	31.1	120	38	303	POO	69.2-283
Copper	20-62	169	7.3	64.2	4.91	214	OIH	18.3-86.3
Lead	nd-12	169	3.5	35	6.74	132	OIH	5.1-26
Mercury	0.13-0.236	169	0.0195	0.26	0.004	6.05	OIH	0.1-0.2
Nickel	77-115	169	4.8	97	0.89	140	OOH	50.9-238
Selenium	nd-6.6	167	0.14	5	0.1	2	RIH	0.6-2.6
Silver	nd-0.64	169	0.015	2.4	0.038	14	OIH	0.2-1
Zinc	91-147	169	36.3	135	31.5	566	OIH	60.8-288
Organics (ug/kg dw)								
Diesel Range Organics	-	93	6	35	-	-	-	-
TPH	-	76	9	65	-	-	-	nd-17.1
LPAHs	nd	152	5.5	1,298	50	13,993	POSF	nd-77
HPAHs	nd-220	152	13.6	2,749	320	36,985	POSF	nd-115
PAHs	-	152	20.0	4,047	-	-	-	nd-192
Aldrin	-	169	0.09	3.6	-	-	-	nd
Dieldrin	nd	169	0.08	2.4	15	43	RIH	nd
Total BHCs	-	167	0.38	22.25	25	25	RIH	nd
Total DDTs	nd	167	1.035	23.75	0.2	280	RIH	nd-2.1
Total PCBs	nd	167	5.6	143.5	61	149	OOH	1.9-3.9
Tri-n-butyltin	-	117	0.1625	38	-	-	-	nd-1.3

nd: not detected All calculations made using 1/2 of the reported detection limit for values below detection.

[1] OIH = Oakland Inner Harbor; OOH = Oakland Outer Harbor; POA = Port of Oakland; RIH = Richmond Inner Harbor; POSF = Port of San Francisco

Appendix Table 3

Year	Project	Bin Volume (cy)
1995	Port of Oakland 42 Ft Deepening	243,980
1996	Port of Oakland 42 Ft Deepening	1,022,254
1997	Port of Oakland 42 Ft Deepening	3,689,426
	Port of Richmond 38 Ft Deepening	953,438
1998	Port of Oakland 42 Ft Deepening	682,185
	Port of Richmond 38 Ft Deepening	1,879,399
1999	Oakland Inner and Outer Federal Channel	350,200
2000	Oakland Inner and Outer Federal Channel	380,650
2001	Oakland Inner and Outer Federal Channel	242,195
	Richmond Inner Federal Channel	454,677
2002	Bay Bridge	272,911
	Oakland Inner and Outer Federal Channel	312,460
	Richmond Inner Federal Channel	262,713
2003	Oakland Inner and Outer Federal Channel	451,500
	Richmond Inner Federal Channel	600,785
2004	Bodega Bay	105,000
	Port of Oakland Inner and Outer Federal Channel	165,000
	Port of San Francisco Pier 35	68,000
	Richmond Inner Federal Channel	108,000
2005	Port of San Francisco Pier 35	40,000
	Port of Oakland Berth 30	109,600
2006	Port of Oakland 50 Ft Deepening (3D)	253,802
	Port of Oakland 50 Ft Deepening (3E)	98,000
	Port of San Francisco Pier 27	71,340
	Port of San Francisco Pier 35	54,000
	Richmond Inner Federal Channel	601,160
2007	Port of Oakland Berths	21,600
	Port of Oakland 50 Ft Deepening (3D)	98,400
	Port of Oakland 50 Ft Deepening (3E)	714,000
	Port of San Francisco Pier 35	87,900
	Richmond Terminal 3	24,600
	Richmond Inner Federal Channel	479,400

Year	**Project**	**Bin Volume (cy)**
<u>2008</u>	Port of San Francisco, Pier 35 E&W	57,000
	San Francisco Drydock, BAE Systems	21,336
<u>2009</u>	Chevron Richmond Long Wharf	50,940
	Valero Refinery Terminal	7,800