

Clean Estuary Partnership Project 4.26

**Multi-Box Contaminant Transport Model and Multi-Year
Sediment Sampling Strategy**

**Sampling and Analysis Plan
for
Sediment Cores in San Francisco Bay**

Prepared by

Applied Marine Sciences and the

San Francisco Estuary Institute

Document Review/Development History	
Technical Committee Approval of Plan	
Technical Committee Review of Draft Plan	
CFWG Review of Draft Plan	
Revised draft for Review by Project Team	July 20, 2005
Internal draft for Review by Project Team	June 1, 2005
Initial concept review by Contaminant Fate Work Group	March 15, 2005
Project 4.26 Scope of Work Approved	February 2, 2005

INTRODUCTION

This sampling plan for collection of sediment cores from San Francisco Bay (the Estuary) and chemical analyses of these cores for pollutants and radiodating has been prepared pursuant to Subtasks 4.1 and 4.2 of Clean Estuary Partnership (CEP) Project 4.26 (*Multi-Box Contaminant Transport Model and Multi-Year Sediment Sampling Strategy*). Analysis of sediment cores from San Francisco Bay is a key task in Project 4.26, and the CEP has budgeted \$200,000 and the Regional Monitoring Program (RMP) \$100,000 for this effort.

Technical oversight/peer review for the project is being provided by the Contaminant Fate Work Group (CFWG) of the RMP, a group of local and national experts in estuarine modeling and sediment analysis. With the advice and review of the CFWG, project plans and reports are delivered to the CEP Technical Committee and the RMP Technical Review Committee for approval. Prior to conducting the sampling and analysis of sediment cores, the scope of work for Project 4.26 called for the preparation, review, and approval of this Sampling and Analysis Plan (SAP).

BACKGROUND

CEP Project 4.26 is a systematic multi-year program, building on model development efforts already underway, to construct a basic mechanistic model that will advance our understanding of contaminant behavior in the Estuary and provide a new tool for water quality management. To achieve these ends, it was expected that the project would identify a field study to reduce uncertainties in the model, and then plan and conduct the field work. This SAP has been prepared to present: (1) the rationale and objectives for the field sampling program; (2) the methods to be used and analyses to be conducted; and (3) the schedule and budget for completion of these tasks.

A conceptual draft plan was reviewed by the CFWG on March 15, 2005. The CFWG agreed that the scarcity of data on sediment processes and pollutant distributions in deeper estuarine sediments represent gaps in our knowledge that lead to large uncertainties in our ability to predict future pollutant concentrations. The existing data set includes detailed analysis of two cores taken from depositional locations in the Estuary (Hornberger, Venkatesan, and Fuller, 1999), with limited data on selected pollutants for a number of other sites. Another depositional core recently has been analyzed in the South Bay for mercury (C. Conaway, UC Santa Cruz, pers. comm). There also have been pollutant core data collected for specific contaminated sites (e.g., Hunter's Point), but those sites are not expected to be representative of the Estuary in general and thus are of limited usefulness for understanding Estuary-scale processes. Pollutant concentrations in cores taken for dredging projects also are measured, but the samples are composited, so

DRAFT

changes in concentration with depth and information on deposition history and sediment processes are lost.¹

The CFWG also concluded that budgetary limitations would prevent Project 4.26 from achieving a statistically robust sampling program. It is costly to collect cores and then conduct chemical analyses on many sections. Given the high variability in chemical concentrations documented by the RMP in surficial sediment samples collected in the Estuary during the last decade, it seems reasonable to expect similar variability in the results from cores. The CFWG consequently did not think it wise to prepare a sampling plan based on the assumption that a few cores would be able to represent a central tendency for a statistical stratum.

Instead, the CFWG recommended a hybrid sampling plan, in which some sites are selected to verify or refine key model assumptions or predictions, with the remainder of sites distributed geographically in particular sediment regimes (i.e., depositional vs. erosional) to improve the relatively poor characterization of pollutants with depth in the sediments of the Estuary. This hybrid approach builds anecdotal but useful understanding of past and current environmental processes in the short term, while moving towards a more statistically robust characterization of the ecosystem for the future.

Based on this recommendation, this SAP has adopted four objectives that are used to identify the location for the sediment cores. The plan then describes: (1) how the cores will be collected, sectioned, and chemically analyzed; (2) a data analysis approach; and (3) a budget and schedule for the work described.

SAMPLING PROGRAM OBJECTIVES

Although existing models can draw upon a large pool of data available for characterizing surface sediment concentrations (e.g., RMP, NOAA/EMAP), as noted above there are far fewer data for characterizing pollutants at depth. Improved data are required to better quantify the pool of legacy and emerging pollutants in the Estuary, verify certain model parameters, and test model results against field data.

The collection of sediment cores and analyses for pollutants and radioisotopes will be used to achieve the following four objectives: (1) describe the potential load to the Estuary from pollutants presently buried but likely to be exposed by erosion, (2) verify the historic loading of pollutants to the Estuary and how those loads have changed in the last several decades, (3) provide an authoritative analysis of contamination with depth that can be used to assess future changes, and (4) provide valuable data for parameterization and evaluation of the multi-box model.

¹ Another CEP project (*Analysis of Pollutants in Sediment Cores Near Storm Water Inputs* [#4.10b]) collected pollutant cores in nearshore locations that were expected to be highly contaminated, and these cores were similarly composited. This project report is available at: <http://www.cleanestuary.org/publications/files/CEP%5F4%2E10B%5Freport%2Epdf>.

Objective #1: Describe future load due to erosion of contaminants now buried

After decades of accumulating sediment as a result of hydraulic gold mining and other activities in the watershed, many areas of the Estuary have transitioned into an erosional regime (Cappiella 1999; Foxgrover 2004; Jaffe *et al.*, 1998). The limited existing data document higher concentrations of pollutants at depth in sediments that may be exposed by erosion and bioaccumulate. This stock of buried contamination is thus a possible “source” of pollutants to biota in the future, as has been described in the recently completed TMDL for Mercury in San Francisco Bay (Looker & Johnson, 2004).

To address this objective, cores must be taken from erosional areas in different Estuary segments to characterize future pollutant “loads” from sediment that could be eroded and redistributed throughout the Estuary. Although past behavior is not a definitive indicator of future trends, areas of recent historical erosion would suggest the most likely locations of continuing erosion, barring major changes in hydrology or sediment loading.

Objective #2: Verify the historic loading of contaminants to the Estuary and how those loads have changed in the last several decades

The present version of the multi-box model relies on national historical estimates of pollutant production and use (Breivik 2002), scaled proportionally with population data to generate estimated historical loads for watersheds. While providing a useful starting point, large uncertainties arise from the use of national data to estimate local pollutant sources and transport. These uncertainties could explain a significant fraction of the difference between model predictions of pollutant distribution and ambient measurements (over-predicting South Bay concentrations, under-predicting North Bay concentrations).

To address this issue, cores should be taken from locations with consistently depositional histories. The data gathered from these cores then could be used to revise the historical loading estimates used in the historical model runs (“hindcasts”). These depositional cores could be taken in either deep-water areas or wetlands. Sediment cores from deep-water depositional areas are more subject dredging, fishing operations, the passage of large vessels, and other disturbances, and thus can be difficult to analyze chronologically. Cores from selected wetlands along the margins of an estuary segment will represent material transported from nearby tributaries combined with near-shore bottom sediments resuspended by wind, wave, and tidal action. This plan proposes to take depositional cores primarily from wetland sites to increase the likelihood of obtaining an undisturbed depositional chronology, despite the larger influence of tributary loads as a confounding factor.

Wetland areas, especially vegetated wetlands (tidal or seasonal) that are less subject to scouring and erosion than channels and banks, might also provide a record of historical changes in pollutant loads for specific watersheds. These data would be valuable for tracking the past changes in loading of PCBs and other pollutants from watersheds and in making predictions of future changes in loads. Prediction of future loads is an important input to the model for predicting future Estuary response.

DRAFT

Objective #3: Provide an authoritative analysis of contamination with depth that can be used to assess future changes and can be enhanced with future sampling

The CFWG noted that obtaining data from one or two dozen cores, although an improvement in the current state of knowledge (e.g., the two USGS cores for PCBs), would likely still not be representative of the Estuary given the variability seen in surface grab samples from RMP and NOAA/EMAP. The CFWG therefore suggested the sampling plan also should include the long-term goal of representatively characterizing the Estuary. If sediment cores can be taken periodically in the coming decades at sites complementary to those taken in this sampling exercise, the long-term data set generated would be valuable for generally characterizing the Estuary and assessing trends.

In addition, the CFWG encouraged consideration of the field sampling as an end in itself. While initial model performance has been promising, they advised that future model refinements possibly could lead to poorer performance (e.g., increasing model complexity and data needs without appreciably reducing uncertainty or even increasing uncertainty). In that instance, the field measurements from the cores would themselves be vital technical information for use in policy development (e.g., for estimating ecological risks to biota posed by pollutants in buried sediments).

Objective #4: Provide data for parameterization and evaluation of the multi-box model

Data from cores collected to meet the other objectives also will be used to parameterize the model and evaluate its performance. Pollutant concentrations in cores from erosional areas combined with projected erosion rates provide estimated inputs of future pollutant loads from Bay sediments for modeling. Information from Bay and watershed wetland depositional cores provides evidence for past loads, to verify or refine estimates derived from the data of Breivik (2002). These depositional cores also provide evidence of recent trends in loads that can be used to project baseline loads in the future. Finally, characterization of the distribution of pollutants with depth throughout the Estuary provides data to compare with model hindcasts and to use as initial conditions for model forecasts.

SAMPLING AND ANALYSIS

Sample Site Selection

In order to achieve the objectives discussed above, sites must be distributed geographically in the Estuary and also among sedimentation regimes (depositional, erosional, or neutral) within each geographic area. The Estuary must therefore be divided into groups (also known as “bins” or “strata”) on the basis of net sedimentation and geographic location. Sedimentation rates within the Estuary are not constant within a geographic region, however, but will vary over time due to factors such as climatic

regime or changes in water and land management practices. Sedimentation regime can be inferred from recent bathymetric changes over time where that information is available.

Jaffe *et al.* (1998) have documented bathymetric change over time in the Estuary, and as a first approximation, bathymetric change in recent decades can be expected to continue in the near term. The Estuary can then be divided into three sampling strata showing depositional, erosional or no net change in bathymetry over recent decadal time scales. USGS has developed this information for Suisun, San Pablo, South, and Lower South Bay, and so these segments will be targeted for coring (Figure 1).²

Erosional areas have been identified within each Bay segment by USGS, so a core will be taken in an erosional area within each segment (Table 1). Suisun and San Pablo bays were on average slightly erosional in recent history (1942-1990, and 1951-1983, respectively), so additional cores from erosional areas will be collected in those segments. In contrast, South Bay showed a neutral trend, and Lower South Bay showed slight deposition in the period 1956-1983, so additional cores from neutral and depositional areas will be collected from those segments, respectively. Where possible, samples will be taken from sites previously used by NOAA/EMAP or RMP so that comparable data on pollutants from nearby surface samples will be available (Figure 2).

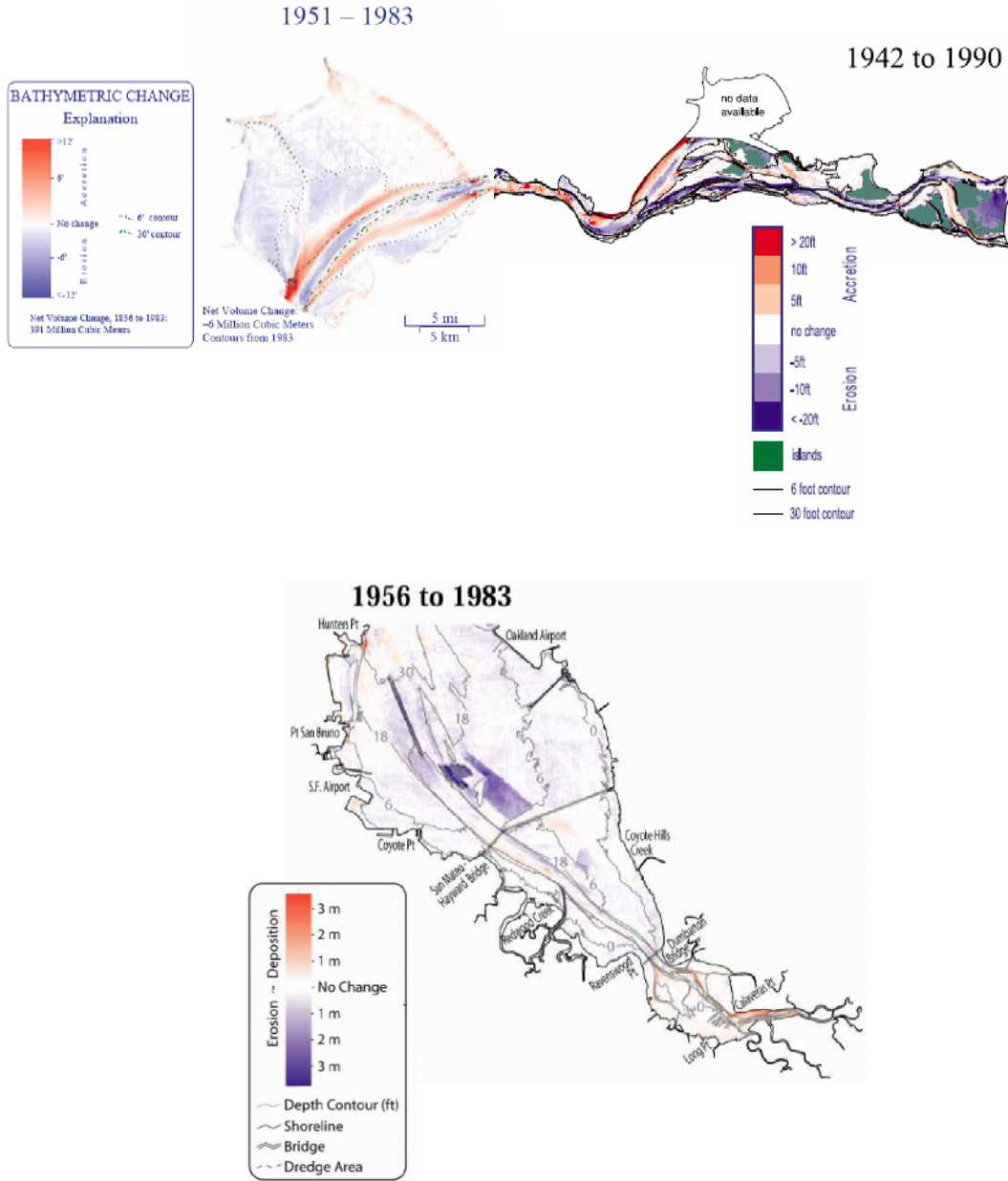
Bay Segment	Sediment Regime (wetlands sites are included as depositional)			Total
	Erosional	Neutral	Depositional	
Suisun Bay	3	-	1	4
San Pablo Bay	3	-	1	4
South Bay	2	1	1	4
Lower South Bay	1	-	3	4
Guadalupe Watershed	-	-		1
Total	9	1	7	17

Table 1. Distribution of sediment cores by Bay segment and sedimentation regime.
 Note that wetlands sites (one for each Bay segment) are included as depositional cores. South Bay extends from San Bruno Shoal to the Dumbarton Bridge, while Lower South Bay is below the Dumbarton Bridge.

Cores from one wetland in each segment on the Bay margins (four sites) will be collected to develop a historical chronology of pollutants in Bay sediments. Historical maps can be used to identify areas that have remained wetlands continuously within these general areas: near the mouth of Guadalupe River or Coyote Creek for Lower South Bay, Outer Greco Island or the mouth of Alameda Creek for South Bay, the mouth of the Petaluma River to western Mare Island for San Pablo Bay, and West Pittsburg to Mallard Island for Suisun Bay (Figures 3 and 4).

² Data on bathymetric change in the Central Bay have yet to be developed, and so depositional, neutral, or erosional areas in this segment cannot be identified for this round of sampling.

Figure 1. Areas of Deposition, Erosion, and No Net Bathymetric Change in Suisun, San Pablo, South, and Lower South Bay. (From Jaffe *et al.* 1998, Capiella *et al.* 1999, and Foxgrover *et al.* 2004.)



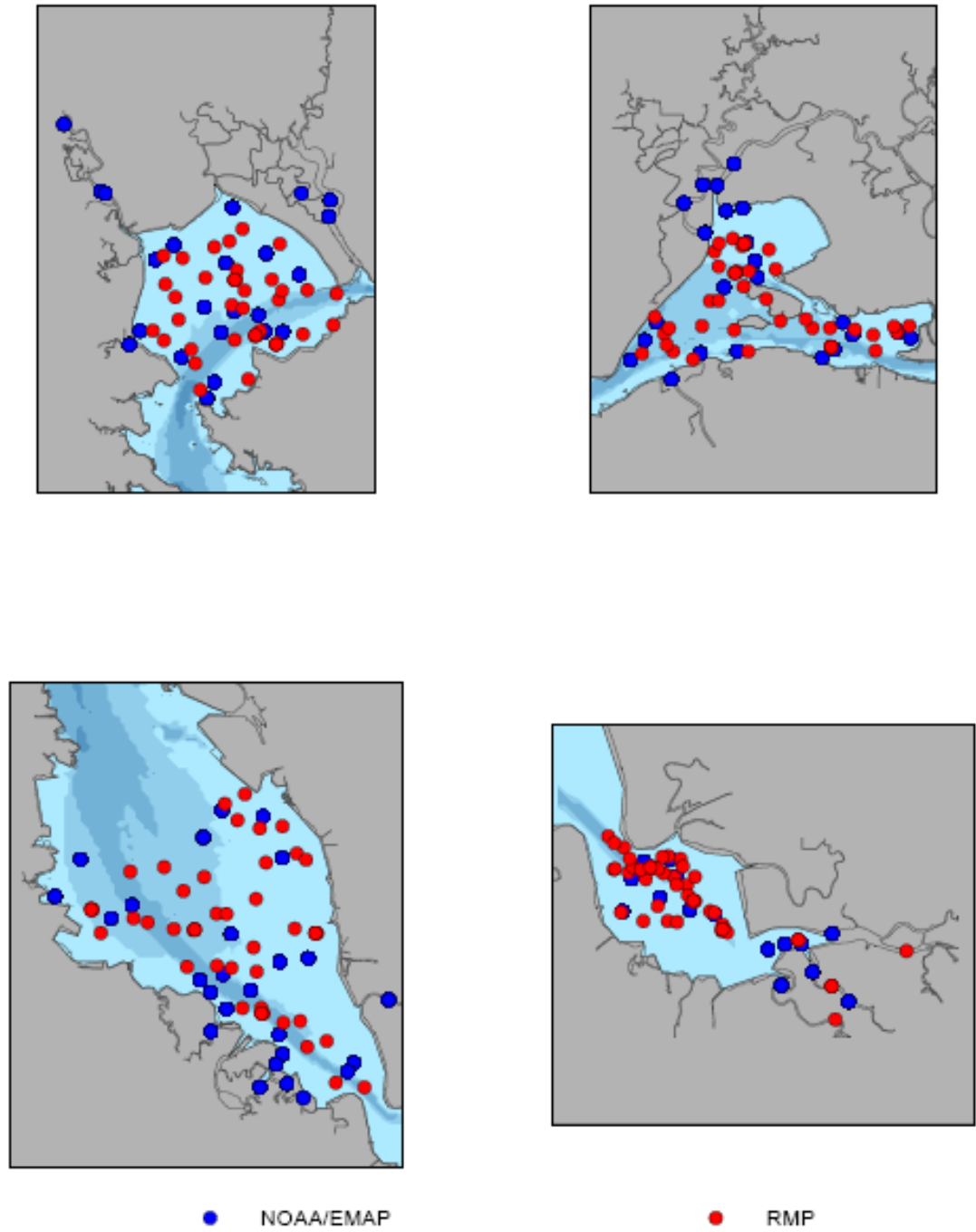


Figure 2. Surface sediment sampling sites of NOAA/EMAP and RMP. Counterclockwise from top right are Suisun, San Pablo, South, and Lower South Bays.

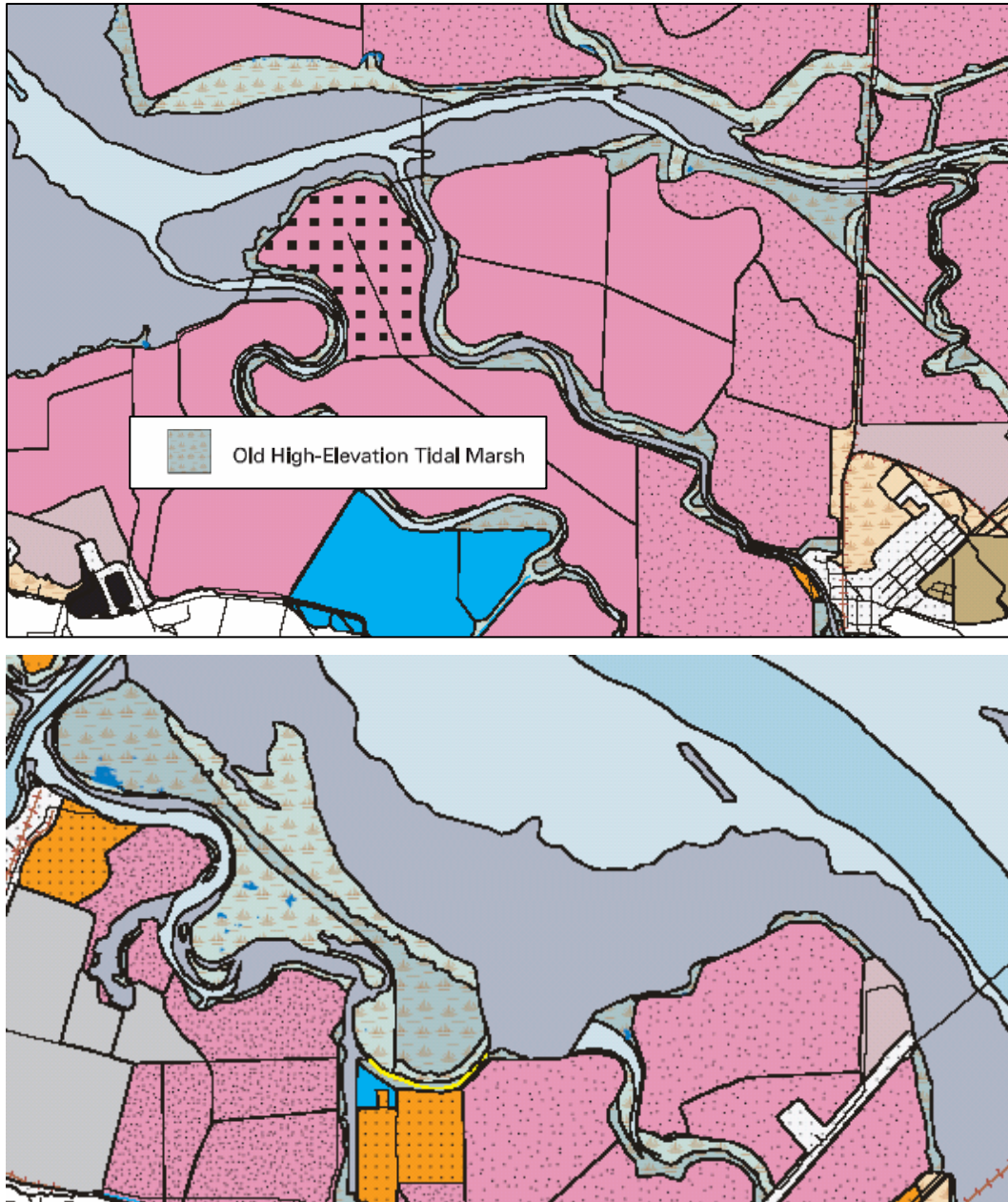


Figure 3. Potential Wetland Sampling Areas in Lower South Bay (top) and South Bay (bottom). Target sites are in old-high elevation marsh.

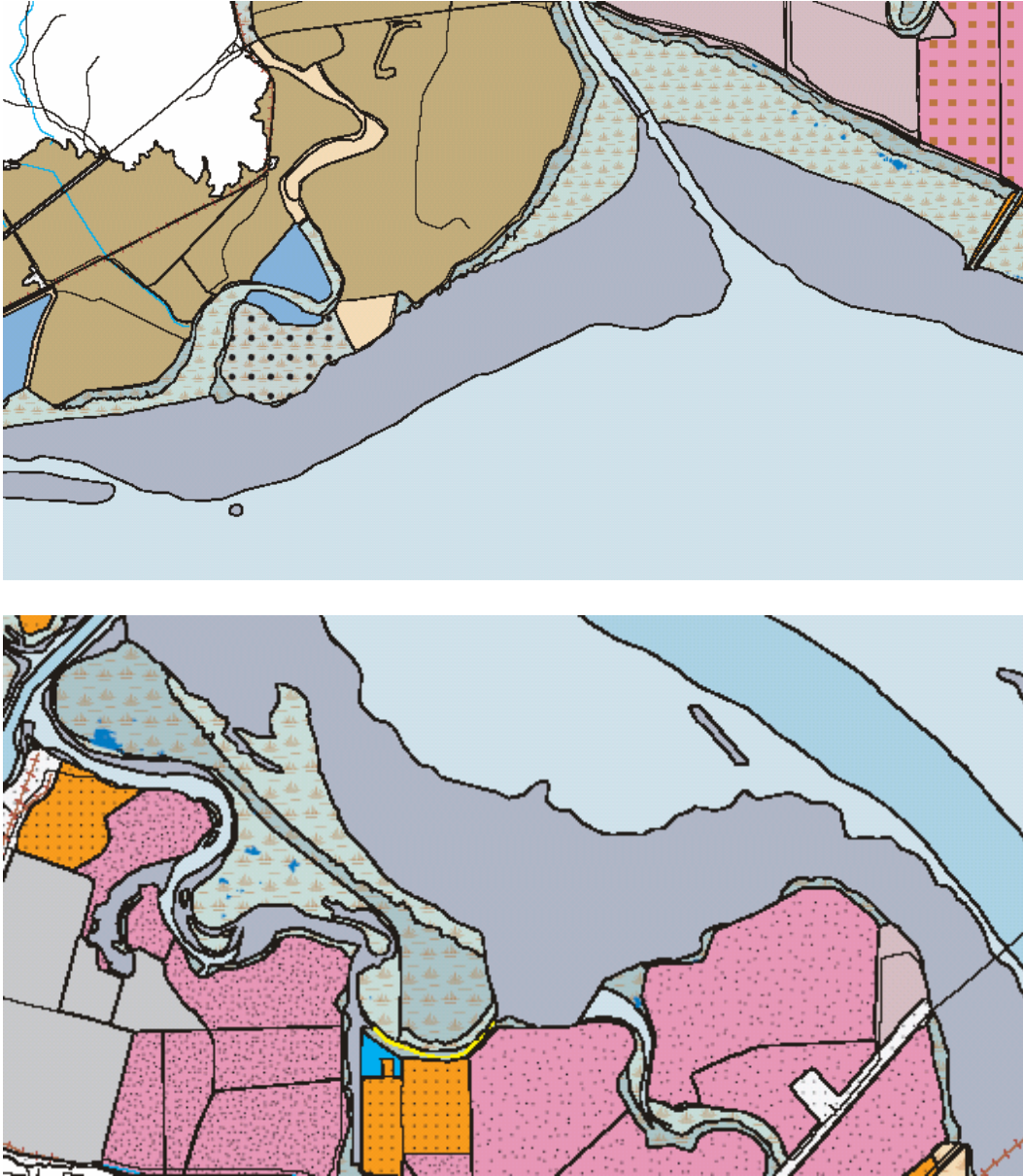


Figure 4. Potential Wetland Sampling Areas in San Pablo Bay (top) and Suisun Bay (bottom). Target sites are in old-high elevation marsh.

For obtaining cores with a recent history of watershed loads, continuously existing wetland areas near the mouth of key tributaries could be used. However, these sites can be difficult to identify as many have been modified (e.g., dredging, levee construction, channel modification). This assessment of past loads is best made in a watershed where current pollutant loads are well characterized, and where historical information regarding wetlands extent is available. The Guadalupe River watershed fits these criteria, so a site at the base of that watershed will be sampled with the goal of estimating a historical trend of contaminant loads from the watershed. Small wetland areas adjacent to the channel have remained unmodified and can provide a depositional history of pollutants from the

Guadalupe, although some influence of Bay sediments (larger for sample sites further downstream) may confound efforts to attribute loads to the watershed.

Core Collection

Changes in bathymetry for Bay sites within a 3-4 decade period (e.g., 1950s to 1980s by Jaffe *et al.* 1998) range up to 3-4 m, with some of the larger changes the direct result of human activities (e.g., channel deepening, borrow pits for fill material, dredge material disposal). However, a majority of the area within the Estuary exhibits a change in bathymetry over this time of about 1 m. Since one aim of modeling efforts is to reconstruct and then predict the long-term fate of pollutants over periods of decades to a century, taking sediment cores up to a depth of two meters should capture a large portion of the sediment activity that occurred over that time scale for most sites.

Cores will be obtained at the 12 Bay sites using a vibracore operated from the *RV Endeavor*. Four-inch cores will be collected from Bay sites. When cores are recovered, they will be kept vertical to minimize disturbance of surficial layers until after overlying water can siphoned off. The cores then will be cut into the maximum lengths that will fit into a large cooler, capped and frozen upright in a rack made of PVC pipe large enough to hold the core sections and dry ice. After they are frozen, cores will be transferred into standard coolers with dry ice.

Cores will be obtained at the four wetland sites and Guadalupe River using either a portable vibracore or a piston core. Coring equipment will be taken to each sampling site either in a small boat or by wheeled vehicle. Road access using a vehicle is preferred because of the volume of equipment that will be needed on-site. The wetland and Guadalupe River cores will be two inches in diameter and two meters long. They will be handled and processed upon recovery using the same procedures as for the Bay cores.

All cores will be kept frozen in a commercial cold storage facility until they are processed in the laboratory. Laboratory processing will consist of sectioning at the specified depth intervals to obtain sub-samples for chemical analyses (see description below). Sub-samples will be shipped frozen to the appropriate analytical laboratory for analysis. All shipping and analytical procedures will be consistent with those used by the Regional Monitoring Program. A duplicate core will be taken at each location and archived.

Sample Analysis

Core sectioning. Cores initially will be sub-sampled at large intervals (e.g., at 10 and 100 cm depth) for radiodating to identify sediment layers for more detailed radiodating and subsequent pollutant analysis. The detailed sectioning for each individual core will be focused on the last 60-150 years. Within this region, additional sections will be taken at intervals to characterize sediment age and pollutant concentrations (1940s – present for PCBs and organochlorine pesticides, ~1850 – present for mercury, ~1970 – present for

DRAFT

PBDEs [in some cores]). Up to 10 sections will be taken from each core for radiodating and chemical pollutant analyses. Section sizes will be a minimum of 1 cm, larger as needed depending on the quantity of material required for sufficient analytical sensitivity to measure parameters of interest (see below).

Chemical and isotope analysis. Radioisotopes will help us to determine the age of sediments at various depths within cores, allowing reconstruction of historical pollutant concentrations in sediments. A uniform pollutant depth profile might result from either mixing or constant loading over time, but the age of the sediment determined by isotopes would distinguish the two scenarios. Isotopes such as ^{137}Cs and ^{210}Pb have half-lives suitable to distinguish among sediments deposited from different decades, and erosional or mixing processes can be seen in discontinuous or uniform age profiles with depth. ^{210}Pb would be more useful for sediments extending prior to the advent of atomic bomb testing. The generally preferred (for cost, speed, and ease) method for ^{210}Pb measurement by several commercial labs (Mycore Scientific, Science Museum of Minnesota) is through separation and alpha counting of progeny isotopes (e.g., ^{210}Pb). A minimum of 1g dry weight sediment for each section is generally requested for radiodating.

If the age distribution of sediments in cores is found to be fairly uniform, chemicals can be analyzed at larger intervals. In contrast, cores showing large changes in age with depth will require sectioning and analysis at smaller intervals to better resolve the distribution of pollutants. For PCBs and PBDEs, the analytical laboratory performing sediment analyses for the RMP (East Bay Municipal Utility District) requires ~10g wet weight of sediment (about 5-7g dry weight). Laboratory requirements for total mercury are about 0.6-1.0 g wet weight.³

Sediment pollutant concentrations often covary with sediment quality characteristics such as TOC and the percentage of fine-grained sediments due to physical and chemical partitioning, so analysis of these parameters will be included to aid interpretation of pollutant concentrations. Optionally, if there is remaining budget (or through reduction of the number of sites or sections to be analyzed for other pollutants), PBDEs may be analyzed in a number of cores. More recently deposited sections of depositional sites to confirm estimated past loads would be the best candidate for these analyses given limited resources. Sections also can be stored frozen to analyze at a later date for many of these pollutants, as degradation and loss rates from frozen samples are negligible. Those sections could be analyzed in future years should additional funds become available.

Data Analysis

The small number of samples and likely poor statistical power are not expected to support robust statistical evaluation of differences in sediment core characteristics for different

³ Because sulfides in anoxic sediment layers inhibit methylmercury production, analyses will be of total mercury rather than methylmercury in cores.

DRAFT

sedimentation strata and segments. However, sample results can be used for addressing the objectives of the project described above. While it is not possible to predict exactly all the analyses that will be conducted until the data are available, the following discussion is meant to provide a description of how expected results will be analyzed to achieve each objective.

Objective #1: Describe future load due to erosion of contaminants now buried.

Pollutant profiles in cores from erosional areas, combined with projected erosion rates in those areas, can be used to project loading from the buried sediment pool in each segment. In erosional Estuary segments where multiple erosional cores are collected, data from individual cores can be combined (with caveats on “representativeness”) to estimate quantities of sediment pollutants eroded. The potential pollutant loads from redistributed sediment can be estimated either through use of the pollutant profiles in the multi-box model, or more directly calculated through a simple empirical model.

Although profiles may not be identical even among erosional areas within a single segment, even a single erosional core from each segment represents a vast improvement over the current situation where extrapolations are made from two depositional locations to the whole Estuary.

Objective #2: Verify the historic loading of contaminants to the Estuary and how those loads have changed in the last several decades.

Cores from wetlands in each segment on the Bay margins will provide historical trends of pollutants in near-shore sediments. These will be compared to deposited Bay sediments from the same time periods (i.e., core sections of similar age) where data are available to identify similarities or differences in pollutant distributions that may provide information on sources or transport processes. For example, if wetland cores have higher pollutant concentrations, it may suggest either a nearby source, or partitioning and transport processes that fractionate pollutants preferentially in materials that deposit in wetlands (uncertainty in radiodating could make such comparisons difficult.) Grain size and TOC data will provide further information that will help identify these possible confounding factors.

Pollutant concentrations and sediment accumulation rates in surface sediments from the Guadalupe watershed core will be compared to recently measured loads to understand the current relationship between deposited wetland sediments and exported loads. For example, pollutant concentrations in the core could be biased consistently high relative to the concentrations in suspended sediments in the riverine discharge. Such a relationship, combined with the historical wetland deposits, can then be used to improve historical estimates of pollutant loading from the watershed.

Wetlands core data also will be used to verify model expectations of pollutants in transported sediments for those periods. For example, if wetland cores do not show pollutant concentrations that mirror quantitatively or qualitatively the historical expectations, then adjustments to refine the model may be warranted (e.g., introducing a time lag between use pattern changes and watershed loading signals, or reallocating

DRAFT

historical loads among watersheds or bay segments based on differences in deposited sediments). While there is always a danger of attempting to infer too much from a limited number of cores, the additional information will represent a large improvement over the current state of knowledge. Obtaining supporting information (e.g., different periods of development in various areas around the Bay, or the presence of specific pollutant sources in some watersheds) would provide additional confidence that such model adjustments would be warranted through support by multiple lines of evidence.

Objective #3: Provide an authoritative analysis of contamination with depth that can be used to assess future changes and can be enhanced with future sampling.

Collecting and analyzing cores will improve the present characterization of pollutant distributions in the Estuary. Sediment pollutant distribution and age profiles will serve as important elements in characterizing the current condition of the Estuary to supplement past and planned surface sediment sampling. In combination with surface pollutant distributions, the core data serve as our starting point for evaluating changes, both in estimating the initial pool of pollutants, and in our understanding sediment processes (e.g., the range of mixing depths encountered, spatial differences in pollutant sources and sediment characteristics and processes). Future work will collect and analyze surface samples and ideally cores from additional sites to continue improving our understanding of the Estuary through more spatially representative sampling of the system.

In addition to their use in pollutant mass balance modeling, the measurements from the cores would themselves be vital technical information for use in policy development, e.g. for estimating risks posed to deeper residing benthic organisms by pollutants distributed in sediments below the surface 5cm typically sampled.

Objective #4: Provide data for parameterization and evaluation of the multi-box model.

The information derived from analysis of the cores described above will serve also as data for inputs or as verification of various portions of the multi-box mass budget model (the data are not, however, constrained for use with any particular model). As described above, data from erosional areas can be used in estimates of pollutants reintroduced by sediment erosion and resuspension. Data from depositional cores can serve to verify or refine historical pollutant concentrations and sedimentation rates in different areas of the Bay. The age and distribution of pollutants in individual cores can also be compared to those predicted in mass budget modeling for hindcast runs. Pollutant distributions with depth can be used to initialize the model for forecast runs, and anticipated trends in loading (extrapolated from past loads) are also important inputs to these runs.

However, care must be taken not to over-interpret or attempt to fit the multi-box model too tightly to the core data, given their limited representativeness, and given some simplifications used in the modeling that likely would not be reflected in the field samples. For example, the multi-box model subdivides Estuary segments into surface boxes that run shore to shore, whereas there likely are differences and asymmetry in loading sources, sediment processes, and bathymetry from one shore to the other within each of the model boxes in the Bay. Attempting to fit a model too tightly to limited data may result in biases that are unknown.

DRAFT

Although USGS cores taken in 1990 in Richardson and San Pablo bays already have provided some evidence of pollutant loading histories, with over a decade since that effort, the new cores will characterize more recent trends, particularly for emerging pollutants like PBDEs. The fewer than 20 cores to be collected in this effort are also not likely representative of the Estuary, but they would represent a major step toward developing a more detailed and accurate understanding of sediment processes and pollutant distributions, as well as for refining and verifying simplistic assumptions and extrapolations currently being used in modeling.

SCHEDULE

A timeline for the various study tasks is indicated in Table 2.

Table 2. Estimated Schedule for Completion of Tasks

Sampling and Analysis Plan Development	March – Sept 2005
Sampling and Analysis Plan Approval	September 26, 2005
Field sampling	October 2005
Initial core sectioning and radiodating.	Nov-Dec 2005
Follow-up sectioning and core dating	Dec-Mar 2006
Chemical (pollutant) analyses	Apr-Jun 2006
Data QC and analysis	Jun-Aug 2006
Draft technical report	Sept 2006
Final report	Dec 2006

BUDGET

The budget presented in Table 3 assumes that the US Bureau of Reclamation boat *RV Endeavor* can be used for sampling. The need to hire a commercial boat for sampling (because of scheduling issues or need for shallower draft) would result in higher costs. Analytical costs are estimates based upon costs from laboratories on previous projects. The sample total in the budget also assumes only 17 sites sampled: 5 wetland sites (4 bayshore and Guadalupe), and 12 in the Bay (4 segments x 1 erosional and 2 “representative” samples each segment). Sampling wetland and/or bay sites in Central Bay would result in somewhat higher sampling costs, and higher analytical costs (proportional to added sample numbers).

Component	Cost	CEP Share	RMP Share
<i>Sample Collection & Processing</i>			
12 bay sites	\$50,680	\$50,680	
4 wetlands + Guadalupe	\$25,800	\$25,800	
<i>Radiochemistry</i>			
Preliminary radiodating 210Pb (2/core, 17 sites)	\$10,200		\$10,200
Follow-up 210Pb radiodating (8/core, 17 sites)	\$40,800		\$40,800
<i>Organic Chemistry</i>			
PCBs (10/core, 17 sites)	\$68,000	\$68,000	
OC Pesticides (10/core, 17 sites)	\$21,250	\$21,250	
PBDEs (10/core, 5 sites)	\$5,400	\$5,400	
<i>Inorganic Chemistry</i>			
Mercury (10/core, 17 sites)	\$18,700	\$18,700	
TOC, grain size (10/core, 17 sites)	\$17,000		\$17,000
<i>Reporting</i>			
Data QC and analysis	\$8,000		\$8,000
Data interpretation/analysis, final & draft report preparation	\$24,000		\$24,000
Contingency	\$10,170	\$10,170	
Total	\$300,000	\$200,000	\$100,000

Table 3. Estimated Project Budget. Analytical costs are estimated as \$300/sample for 210Pb (USGS or USC); \$750/sample for PCBs, PBDEs, and OC Pesticides (EBMUD); and \$110/sample for mercury (Batelle). One contingency day is included in the field sampling budget.

LITERATURE CITED

Breivik, K., Sweetman, A., Pacyna, J. M., and Jones, K. C. (2002). Towards a global historical emission inventory for selected PCB congeners - a mass balance approach. *Science of the Total Environment*, 290, 199-224.

Cappiella, K., Malzone, C., Smith, R., and B. E. Jaffe .1999. Sedimentation And Bathymetry Changes In Suisun Bay: 1867-1990. USGS Open-File Report 99-563. U.S. Geological Survey, 354 Middlefield Road, Menlo Park, CA 94025

Davis, J. A. (2004). Long-term fate of polychlorinated biphenyls in San Francisco Bay (USA). *Environmental Toxicology and Chemistry*, 23(10):2396-2409.

Foxgrover, A.C., Higgins, S.A., Ingraca, M.K., Jaffe, B.E., and R. E. Smith, 2004. Deposition, Erosion, and Bathymetric Change in South San Francisco Bay: 1858-1983 Open-File Report 2004-1192. U.S. Department of the Interior U.S. Geological Survey

Fuller, C.C., van Geen, A., Baskaran, M., and Anima, R., 1999. Sediment chronology in San Francisco Bay, California, defined by ²¹⁰Pb, ²³⁴Th, ¹³⁷Cs, and ^{239,240}Pu, in *The impact of human activities on sediments of San Francisco Bay, California*, van Geen, A., and Luoma, S.N., eds.: *Marine Chemistry*, v. 64, no. 1-2, p. 7-27.

Hornberger, M.I., Luoma, S.N., van Geen, A., Fuller, C., and Anima, R., 1999. Historical trends of metals in the sediments of San Francisco Bay, California, in *The impact of human activities on sediments of San Francisco Bay, California*, van Geen, A., and Luoma, S.N., eds.: *Marine Chemistry*, v. 64, no. 1-2, p. 39-55, doi: 10.1016/S0304-4203(98)80083-2.

Jaffe, Bruce, Smith, Richard, and Torresan, Laura Zink. 1998. Sedimentation and Bathymetric Change in San Pablo Bay: 1856-1983. USGS Open-File Report #98-759.

Looker, R.E., and Johnson, B. 2003 Mercury in San Francisco Bay. Total Maximum Daily Load (TMDL) Project Report. Draft report presented to Stakeholders on July 2, 2003, available at:
www.swrcb.ca.gov/rwqcb2/TMDL/SFBayMercury/SFBayMercuryTMDLProjectReport.pdf

Venkatesan, M.I., de Leon, R.P., van Geen, A., and Luoma, S.N., 1999. Chlorinated hydrocarbon pesticides and polychlorinated biphenyls in sediment cores from San Francisco Bay, in *The impact of human activities on sediments of San Francisco Bay, California*, van Geen, A., and Luoma, S.N., eds.: *Marine Chemistry*, v. 64, no. 1-2, p. 85-97.