

Concentrations of PCBs and Hg in soils, sediments and water in the urbanized Bay Area: Implications for best management



FINAL REPORT

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Summary

Sediment samples were collected from street sides and storm water collection facilities at over 360 locations within the Bay Area, focusing on historically industrial areas. Data on Hg and PCB concentrations measured in these samples support a general hypothesis that pollutant concentrations are elevated in specific parts of the urban landscape.

1. Pollutant concentrations are highly patchy, even at moderate to small spatial (sub-kilometer) and temporal (~annual) scales. This patchiness reflects the episodic nature of many release (e.g. accidental spills) and transport (e.g. storms) events and processes.
2. Concentrations at sites within 3 km of one another exhibit spatial autocorrelation, i.e. show similarities in concentration, which may be due to similarities in land use, activities, or transport of shared pollutant sources.
3. Individual sites and patches most contaminated with PCBs are often not those with high Hg. This is logical given the different use histories and original sources of the substances

Sites with high pollutant concentrations in soil or water found in this and other studies provides a starting point to identify locations (whether single sites or general areas) where management actions could be applied and measured for effectiveness, ranging from tracking the true sources to inline or end-of-pipe treatment before discharge.

Settling experiments were conducted with collected stormwater and sediment samples to examine pollutant partitioning in various aqueous (suspended, dissolved) or solid (bed sediment) fractions. A portion of both Hg and PCBs are in easily removed fractions.

1. A large fraction (30-70%) of total PCBs easily settled out of suspension in stormwater samples quickly (within 20 minutes), whereas a much smaller fraction (10-30%) of Hg was removed.
2. A larger fraction (>90%) of Hg and PCBs (>80%) in bed sediment samples resuspended in water settled out quickly (<10 min).

These results suggest that PCBs are associated with larger and/or heavier particles and will be more effectively removed than Hg by treatment BMPs using settling, centrifugation or related methods. Treatment systems handling both pollutants will therefore likely need to meet more difficult design criteria (e.g. longer settling times, finer particulate removal) for Hg reduction.

No single tool or management option is alone likely to adequately address reductions in mass loads of PCBs and Hg to the Bay for all the scenarios that will be encountered in the region. A combination of institutional controls (e.g. outreach and education), municipal operations (e.g. street sweeping, stormwater collection and conveyance systems maintenance), pollution prevention activities (e.g. recycling, end-of-life disposal), soil remediation and abatement on public and private lots, and treatment controls both local (e.g. block-scale) and watershed scale may be necessary for different situations.

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Introduction

Background

Mercury (Hg) and polychlorinated biphenyls (PCBs) are of current environmental concern in San Francisco Bay due to their lengthy persistence in the environment and their potential to adversely impact humans and wildlife. Knowledge about contamination and effects has been growing since a fish consumption advisory was issued in 1994. The Region 2 Regional Water Quality Control Board (Water Board) has recently developed total maximum daily loads (TMDLs) and basin plan amendments for Hg and for PCBs (SFBRWQCB 2006; SFBRWQCB 2008). These reports use a mass balance approach to compare contaminant loads entering the Bay from various pathways, provide an analysis of linkage between contaminant loads and beneficial uses, and propose load allocations. Both the Hg and PCB TMDLs call for better controls on urban stormwater, with load reductions of upwards of 50% (Hg) and 90% (PCBs). This presents a challenge for urban managers given there is little quantitative information on where high concentrations of Hg and PCBs occur in urban areas and how these might be cost effectively managed to reduce loads to stormwater and ultimately, to the Bay.

Study objectives

A primary objective of this work was to determine the distribution of concentrations of priority pollutants, namely mercury and PCBs, in the urban watersheds of the San Francisco Bay region. If concentrations of pollutants in watersheds (sediments and/or waters) are similar to those in the Bay, reductions in pollutant loading to the Bay could still be accomplished simply through reduction of total sediment and water loads to the Bay. However, to the extent that areas with higher than Bay average concentrations exist and are found, greater reductions in total loads can be accomplished with less effort by focusing on such areas.

The information collected on pollutant temporal and spatial distribution can also be used to determine the appropriate scale of management actions, e.g. where pollutants are highly concentrated and localized, localized actions are best applied, whereas more distributed pollution may be better handled through treatment of aggregated discharges. After these areas of higher pollutant concentrations are found and characterized, in the future a number of these locations can be used by local agencies to pilot test management strategies, as appropriate for those particular sites. Effectiveness of these various strategies on the local scale can then be evaluated to determine their suitability for wider application to similar types of contaminated sites in other areas.

In addition to generally surveying the distribution of pollutants in the watershed at over 360 urban locations, this study included a characterization of the distribution of pollutants in different fractions of sediment and water samples. Samples from four sites with known elevated or consistently quantifiable concentrations of pollutants identified in the general survey were selected to maximize the probability that quantitative data (well above detection and reporting limits) on pollutant fractionation could be obtained. The partitioning of pollutants in environmental materials will affect their transport pathways and thus the suitability of different control strategies, e.g. appropriate settling times, or whether adsorption of dissolved pollutants is needed to obtain significant removal.

Previous local work

In order to better understand sources and loadings of PCBs and Hg in support of the TMDLs, BASMAA sampled sediments in urban stormwater conveyances in 2000 and 2001 (KLI 2001; KLI 2002; Salop et al. 2002a). During that survey a number of conveyances were identified with elevated concentrations of PCBs (Figure 1). In addition, a number of conveyances showed elevated concentrations of Hg (Figure 2). These initial observations led to a number of follow-up surveys (Salop et al. 2002b; STOPPP 2002; San Jose and EOA 2003; STOPPP 2003; STOPPP 2004; Kleinfelder 2005; Kleinfelder 2006; EOA 2007). With the exception of Ettie Street in Oakland

(Kleinfelder 2005), in many cases the elevated concentrations were not replicated; subsequent sampling showed lower concentrations, in some cases below thresholds of concern. Even concentrations of PCBs in Ettie Street pump station in the 2nd year were 3x lower than in the first year of sampling. In addition, in many cases, sources of elevated concentrations could not be identified. Thus, previous data has lead to the conclusion that PCB concentrations in conveyance sediments are highly variable in both space and time. This conclusion is logical given the nature of PCB contamination. Contaminated locations on the landscape (hot spots) may only disperse under certain climatic and local human use conditions. For example continuous low intensity rainfall is likely to transport contaminants off a public or private lot differently from few but higher intensity rain storms. In addition, sedimentation in municipal stormwater system or pump station sump will vary depending on climate and maintenance activities. These variables add challenges to the requirements described by the municipal regional stormwater NPDES permit (MRP) Order No. R2-2009-0074 (specifically C.11.c., C.11.d. (Hg), and C.12.c., and C.12.e. (PCBs), which call for enhanced investigation and abatement of land sources and enhanced contaminated sediment removal from collection systems (SFBRWQCB 2009).

These things said, the persistent presence of PCBs at the Ettie Street pump station led to a successful effort to find sources in the watershed and a pilot scale removal project. The pilot abatement project included inspection and removal of PCB wastes from private lots and removal of contaminated soils from roadsides. In addition, a pilot street cleaning exercise was conducted in 2006, using hydroblasting and removing washed solids and fluids for two areas in the public right-of-way at Helen and Hannah streets. Sediment PCBs were found at that location post abatement (one year later) at concentrations similar to those prior to treatment (Salop 2007), which suggested alternate hypotheses:

1. There have been no or minor inputs of fresh sediment from the target properties to the depositional areas sampled, and samples were collected from the same basic pool of accumulated sediments sampled in 2005 but not effectively removed, or
2. There have been new ongoing inputs of sediments from targeted properties since 2005, and PCB concentrations associated with these new inputs are similar to those sampled in 2005.

Given the fairly aggressive hydroblasting removal effort in 2006, pollutants measured in the followup sampling are unlikely to have come from within the treated sites, so transport from nearby areas is the more likely cause. However it is not possible to entirely discount the first possibility, as no samples were collected or reported immediately after the abatement actions were taken, so within-site transport might still be a component of the pollutants found in followup sampling.

BASMAA data (2000/2001)
(Only sites that exceeded 200 ug/kg are shown)

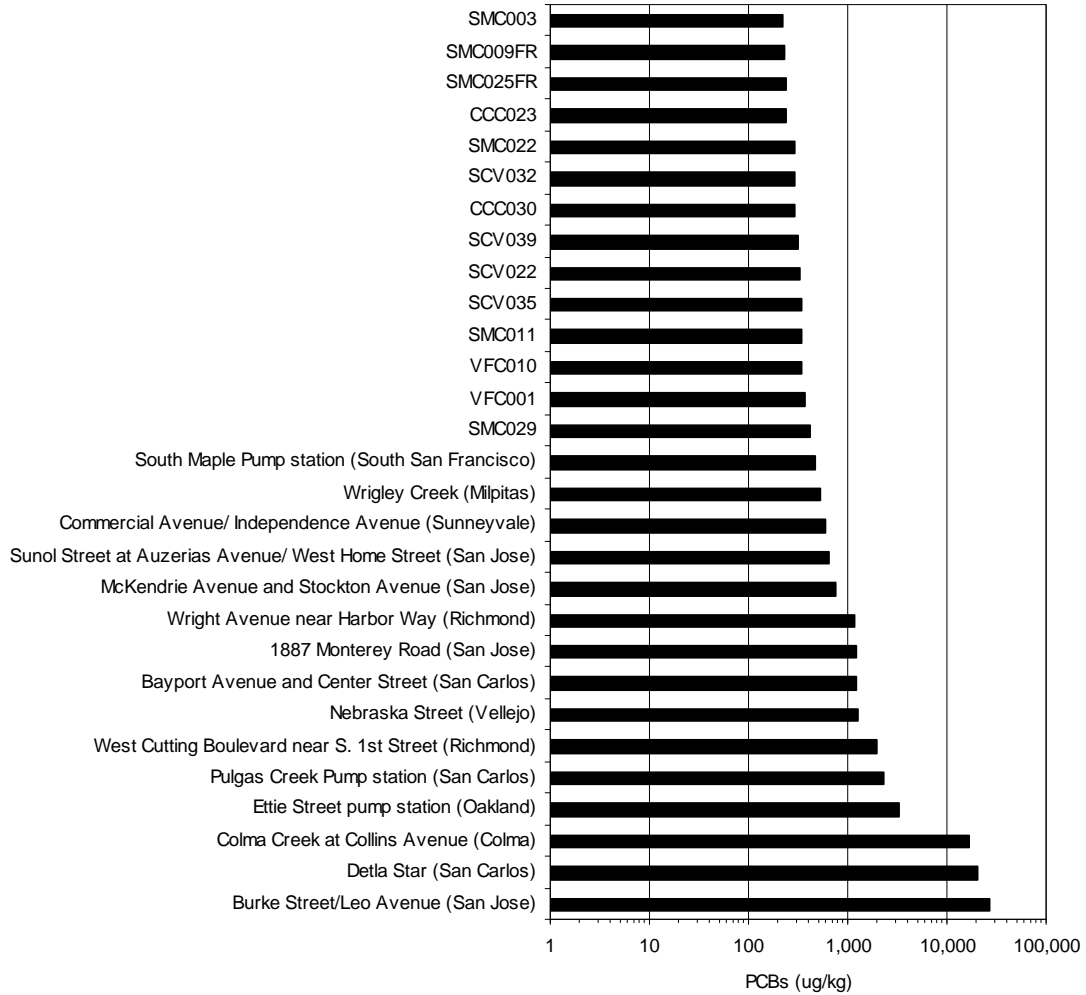


Figure 1. Selected BASMAA 2000/01 stormwater conveyance sediment PCB data

BASMAA data (2000/2001)
(Only sites that exceeded 0.4 mg/kg are shown)

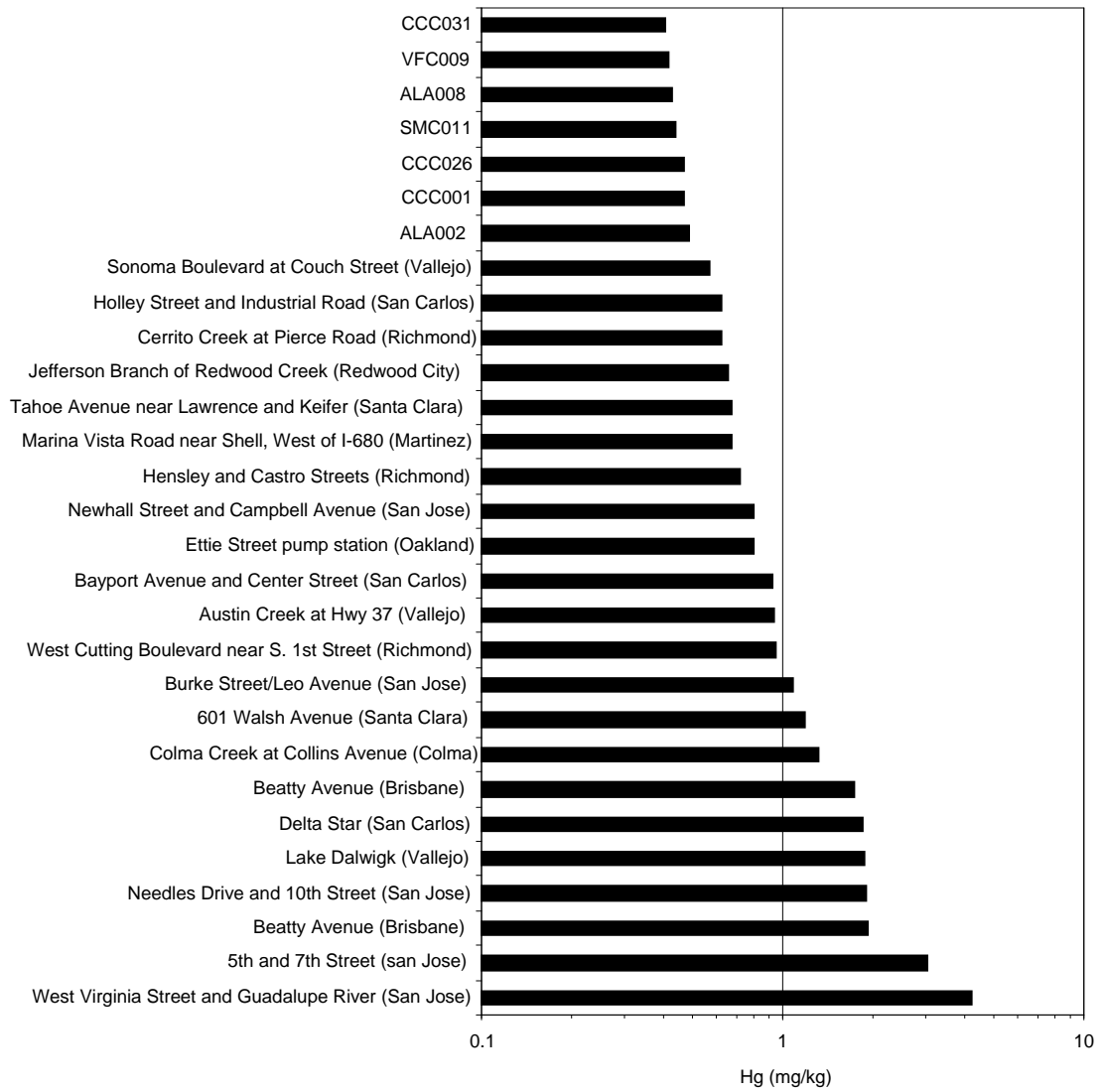


Figure 2. Selected BASMAA 2000/01 stormwater conveyance sediment Hg data

Pollutant Survey

The first goal of this study was to build upon previous work by BASMAA and member stormwater agencies characterizing the distribution of pollutants in watershed areas and stormwater conveyance systems. The previous work indicated that the highest concentration sites were found in industrial, older commercial and residential areas as opposed to lower concentrations in rural areas. This present study focused almost exclusively on industrial and mixed use urban areas.

Site selection methodology

In August to September of 2006, SFEI compiled a number of spatial databases using GIS. The databases included ABAG 1995 land use (in particular, industrial and commercial land use), 1950s urban area (used to determine “old industrial”), 1950s railway lines, auto recycling facilities, PG&E facilities, watershed boundaries, PCB and Hg “hotspots” (from DTSC databases), and BASMAA conveyance bed sediment data. These data sets were analyzed to determine the number or percentages of each factor in each watershed area. The maps and data tables were presented in a meeting with BASMAA and Water Board staff. The objective of the meeting was to use the GIS data and analysis to identify areas for SFEI field reconnaissance before finalizing sample locations. Attention focused on old industrial areas (Figure 3) in the cities of Richmond, San Leandro, Hayward, San Jose, Redwood City, Sunnyvale, San Carlos, and South San Francisco. Following a reconnaissance of these areas by SFEI, a patch in San Bruno was added and Redwood City was dropped. After this first sampling effort, additional areas in the East Bay were selected by a similar methodology, adding sites from industrial areas in Benicia, Berkeley, Concord, Emeryville, Oakland, Pittsburg, Vallejo, and areas in unincorporated Contra Costa County. These sites were sampled in September of 2008.

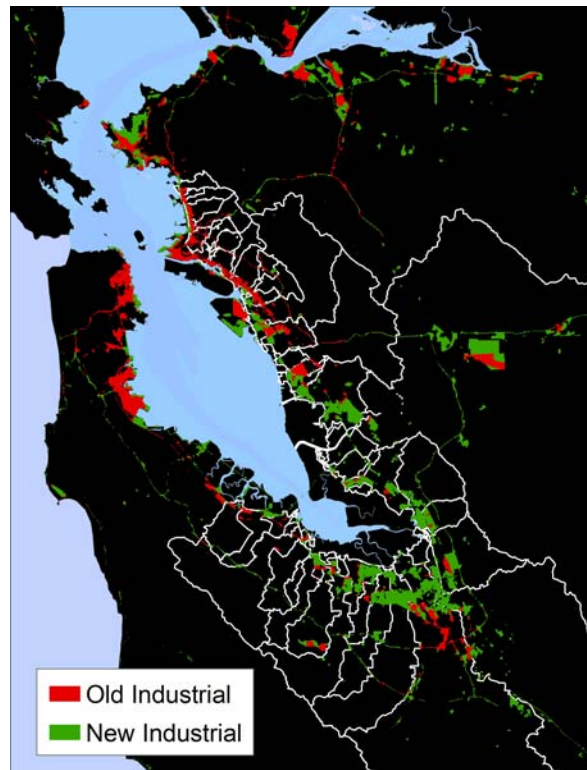


Figure 3. 1950s industrial area (red) and 1995 industrial (green) in the Bay Area

Sampling & analytical methods

Field sampling

During June, July, August, and September 2007, a total of 267 sediment and soil samples were collected from paved street surfaces near the gutter (n=137), inside drop inlets (n=112), the lip of drop inlets without the grate lifted (n=9), road side soils (n=5), driveway sediments (n=1), a composite of sediment from inside a drop inlet and around the lip of a lifted grate (n=1), and type not recorded (n=2). Samples were collected using either a plastic dust pan and horse hair paint brush, or a narrow aluminum scoop constructed to take samples without lifting a drip inlet grate. Between samples, the equipment was washed with detergent (Alconox) and double rinsed in tap water. At each location, a 250 ml (8 oz) sample was collected, placed into the sample jar, labeled and stored on ice. On return to SFEI, samples were refrigerated for storage. Samples were sieved through coarse mesh screens to remove large (>2mm) debris, homogenized, and split into three sub-samples (for PCBs, Hg, and sand/silt analyses), and shipped to the labs with chain of custody (COC) forms. In September 2008, sampling was conducted in additional locations in areas with older industrial sites in the East Bay, with a total of 94 more locations sampled, including within drop inlets (n=53), sediments around inlet grates (n=31), street surface dirt (n=6), driveways (n=3), and one type not recorded. Samples were collected using the same methodology, and similarly sieved to remove large debris (>2mm) before shipment to the analytical laboratories.

Lab analyses

East Bay Municipal Utility District (EBMUD) conducted PCB analyses by EPA Method 8270 (PerkinElmer GC/MS with photo multiplier), modified using an EPA 1668A analytical column and retention times. Individual congener results were reported as ug/kg dry weight with method detection limits (MDL) ranging 0.001-0.056 mg/kg dry weight for individual target congeners. Standard Batch QC samples included method blanks, low-level blank spikes, mid-level blank spikes, duplicates, matrix spikes, and bracketing mid-level check standards. Average relative standard deviations (RSD) on replicates ranged 1-113% for individual PCB congeners; congeners with RSDs above 70% were generally analytes at concentrations near their respective MDLs, and were censored and not included in sums of PCBs. Spiked sample recoveries were within a target range of 65-135% recovery, aside from PCB 209 which was slightly outside that limit (average ~60%) but not censored.

San Jose State University Moss Landing Marine Laboratories (MLML) performed analysis for Hg using EPA 7473: Mercury in Solids and Solutions by Thermal Decomposition, Amalgamation, and Atomic Absorption Spectrophotometry (a.k.a. Direct Mercury Analyzer (DMA)). Prior to analysis, samples for Hg analysis were dried at 60°C for 48 hours. Samples were stored at room temperature before and after analysis. Results were reported in µg/g dry weight with a detection limit of 0.004 mg/kg and a reporting limit (RL) of 0.013 mg/kg. Three method blanks were analyzed with each batch of samples, with results below MDL in all blanks. Sampling and processing equipment blanks were tested to evaluate potential for contamination between samples and from the equipment itself; concentrations averaged <15 ng per sample (~100 g) processed, about 100 times lower than the lowest concentration sample reported (.014 µg/g). One pair of randomly selected analytical duplicates was analyzed with each batch of samples. Relative percent difference was calculated and ranged between 0.6 and 45% (mean = 13%). One matrix spike/matrix spike duplicate (MS/MSD) pair and one SRM sample was analyzed with each batch of samples, with recoveries within target range (75-125%).

Results & Discussion

Concentrations of Hg in Bay Area sediments and soils during this survey ranged between 0.014 and 12.5 mg/kg (summarized by city industrial area in Table 1), with a median concentrations of 0.17 mg/kg. Sums of PCB congener concentrations in Bay Area sediments and soils ranged between the below the method detection limit for all congeners and 7.65 mg/kg. Following conventions used in the Regional Monitoring Program, for the derivation of sums of (“total”) PCBs,

congeners not detected are assumed to have concentrations of zero. If we instead assumed the opposite extreme, that all non-detected PCB congeners are just below their detection limits, a sample with all non-detects could have total PCBs up to 0.073 mg/kg. Thus 0 and 0.073 mg/kg represent the lower and upper bounds of total PCBs for samples with non-detects for all congeners, which applies to slightly over half the samples collected and analyzed in this study.

An alternative way to derive maximum values for non-detects is using the lowest reported result for the most abundant analyte. The lowest result for a sample with a single detected congener was 0.0065 mg/kg for PCB 138. PCB 138 was the most abundant congener, comprising an average 11.7% of total PCBs. Assuming that all other congeners were present at constant percentages relative to PCB 138, total PCBs for that sample with a single detected congener would be estimated to be 0.056 mg/kg. Samples with non-detects for all individual congeners therefore likely have total PCBs less than 0.056 mg/kg (rather than the 0.073 mg/kg sum of detection limits). Although the handling of/assumptions for non-detected congeners can have significant impacts on total PCBs at the lower end of the concentration range, our primary interest was in determining the distribution and abundance of sites with high concentrations.

Most areas had at least one sample site with concentrations higher than Bay subtidal sediment medians (as measured by the RMP Status and Trends monitoring component 2004-2008) of Hg (>0.24 mg/kg), PCBs (>0.005 mg/kg), or both. Mean RMP S&T concentrations were 0.24 mg/kg for Hg and 0.005 mg/kg for PCBs, virtually identical to the medians (within rounding error). The median Hg concentration for these samples at 0.17 mg/kg, was lower than the Bay mean, but the mean was higher, 0.37 mg/kg, reflecting the influence of a few very contaminated locations. The median sum of PCBs in this study was below MDL for all congeners, between 0 and 0.056 mg/kg. Even assuming all non-detects were 0, mean PCBs averaged 0.17 mg/kg, higher than Bay averages using similar assumptions (<MDL = 0), again reflecting the influence of a few very highly contaminated locations. This study did not representatively sample the entire watershed area, focusing on urban sites expected to have higher concentrations. We therefore cannot determine from this data alone whether average inputs from all watershed areas combined would worsen conditions in the Bay. However, for the more polluted areas, it appears that reducing sediment loads with higher than (Bay) average concentrations, especially from a few very contaminated locations, would be particularly beneficial.

Table 1. Concentration ranges (mg/kg, by city industrial area) of Hg and PCBs found in soils and sediments collected in this study during 2007 and 2008.

Area	# Sites	MinPCB	MaxPCB	Min Hg	Max Hg
Albany	2	<MDL	<MDL	0.36	0.73
Benicia	5	<MDL	<MDL	0.10	0.49
Berkeley	13	<MDL	0.46	0.08	1.11
Concord	2	<MDL	<MDL	0.17	0.24
El Cerrito	1	<MDL	<MDL	0.18	0.18
Emeryville	6	<MDL	0.21	0.10	0.27
Hayward	40	<MDL	0.40	0.07	12.54
Oakland	28	<MDL	1.28	0.06	4.85
Pittsburg	9	<MDL	0.08	0.14	0.98
Port of Oakland	15	<MDL	7.65	0.09	3.90
Richmond	39	<MDL	2.26	0.06	1.39
San Bruno	13	<MDL	0.18	0.06	0.36
San Carlos	39	<MDL	2.22	0.04	0.77
San Francisco	12	0.03	1.16	0.05	0.55
San Jose	57	<MDL	0.31	0.06	6.23
San Leandro	40	<MDL	1.27	0.03	1.19
South San Francisco	15	<MDL	0.43	0.01	1.24
Sunnyvale	9	<MDL	1.37	0.07	0.30
Uninc, Contra Costa	6	<MDL	<MDL	0.11	0.86
Vallejo	9	<MDL	0.92	0.08	1.42
75%ile			0.10		0.31

	Median			<MDL		0.17
	25%ile			<MDL		0.11

<MDL = non-detect

Map of pollutant distribution

The spatial distribution and concentrations of total Hg and PCBs measured in collected samples are shown in Figures 4 and 5, respectively, combined with results compiled from previous studies in the region (Gunther et al. 2001; KLI 2002; Salop et al. 2002a; Salop et al. 2002b; STOPPP 2002; San Jose and EOA 2003; STOPPP 2003; STOPPP 2004; Kleinfelder 2005; Kleinfelder 2006; EOA 2007; SFEI 2010). In many cases, locations with high concentrations of one pollutant or the other are clustered together, seen as moderate to large overlapping or concentric circles. In addition to a possible artifact of our sampling design, this may represent a tendency of similar or related business functions to cluster together (e.g. driven by zoning regulations, support infrastructure, competition, or other factors), and/or pollutant dispersion processes (runoff, wind, wheel and foot tracking) within the landscape. On a regional scale, the general areas of highest concentrations for these pollutants are often clustered in different areas.

Spatial autocorrelation, i.e. the similarity of concentrations at proximate sites, can also be illustrated in variograms, which plots average variances between sites separated into various distance bins. For this analysis, data from this study were combined with available data on Hg and PCB concentrations from other local studies used for Figures 4 and 5. Prior to analysis, GPS spatial coordinates data were converted into the Universal Transverse Mercator (UTM) coordinate system to express both x and y coordinates in equivalent distance units (meters). Concentrations were converted to log-transformed values, with non-detects replaced by simulated values in a lognormal distribution with a geometric mean of the lowest reported value (0.0002) using the log-standard deviation of the reported PCB results (SD on a log-scale of 0.91).

For samples that are spatially independent and uncorrelated, the variance will be independent of the separation distance. In Figures 6 and 7, variograms (generated using R software) for Hg and PCBs are shown respectively. The line represents a loess fit (locally weighted scatterplot smoothing) of the data for illustration. There appears to be spatial autocorrelation at separation distances of 2500 m or less for both pollutants. However, in many cases locations with moderate to high concentrations of a pollutant are found isolated from other polluted locations, representing isolated specific sources and/or release events. In some cases this may arise because no other samples are distributed inside of the distance where we would expect spatial autocorrelation, while in other cases even inside that distance the inherent patchiness of concentrations due to spatial and temporal variability will cause site concentrations to vary widely. These compare closely with the hypothesis (McKee et al. 2006) that suggested (based in literature review of urban soil concentrations) that the halo around a hotspot averages about 3,000 m for Hg, however it differs from the hypothesis for PCBs which was 300 m (McKee et al. 2006). The hypothesis for PCBs may have been biased low due to a propensity of research literature to discuss very contaminated sites. In hindsight, it appears that the reported literature may not be representative of general industrial areas.

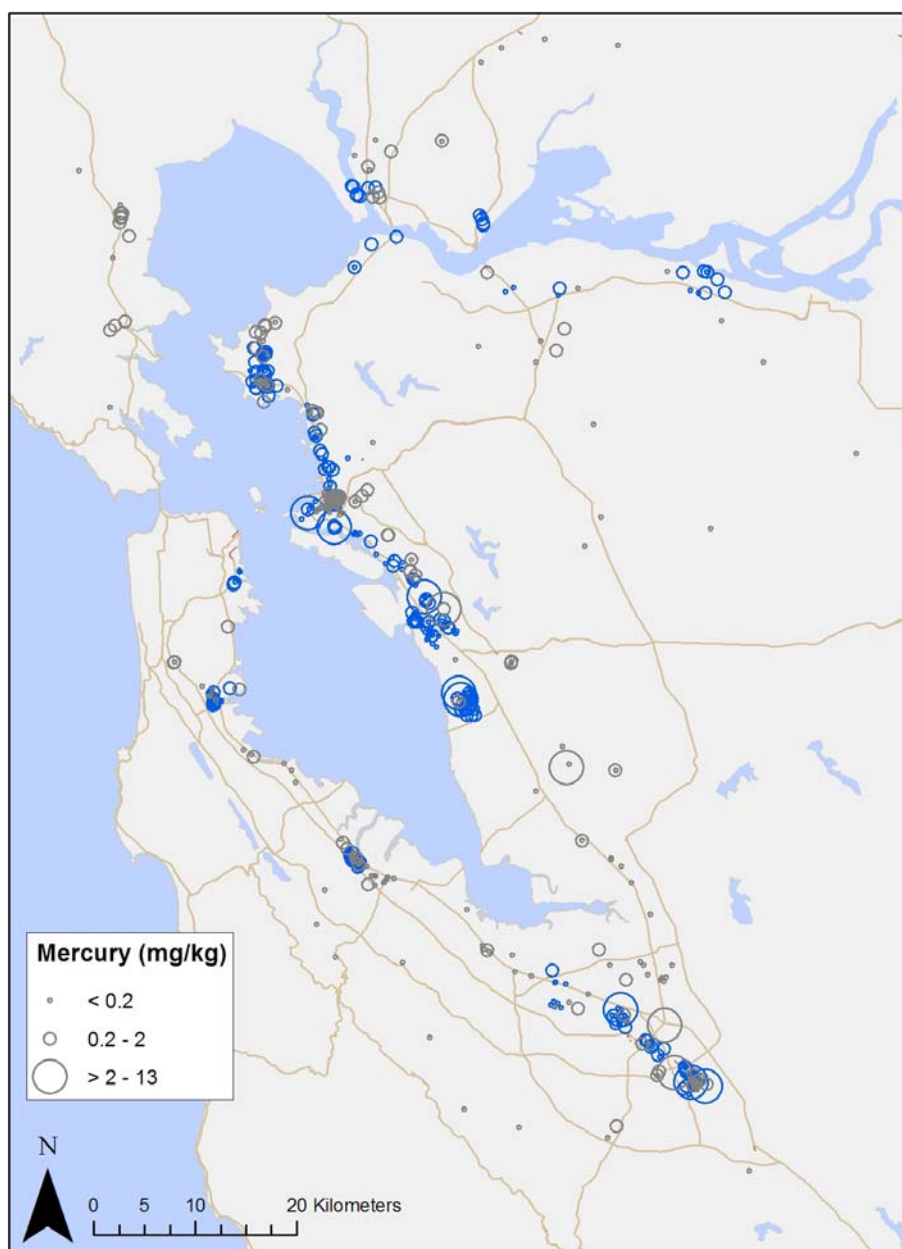


Figure 4. Particulate Hg concentrations sampled in storm collection facilities and streetside soils in the Bay Area in this study (blue symbols) and others (grey).

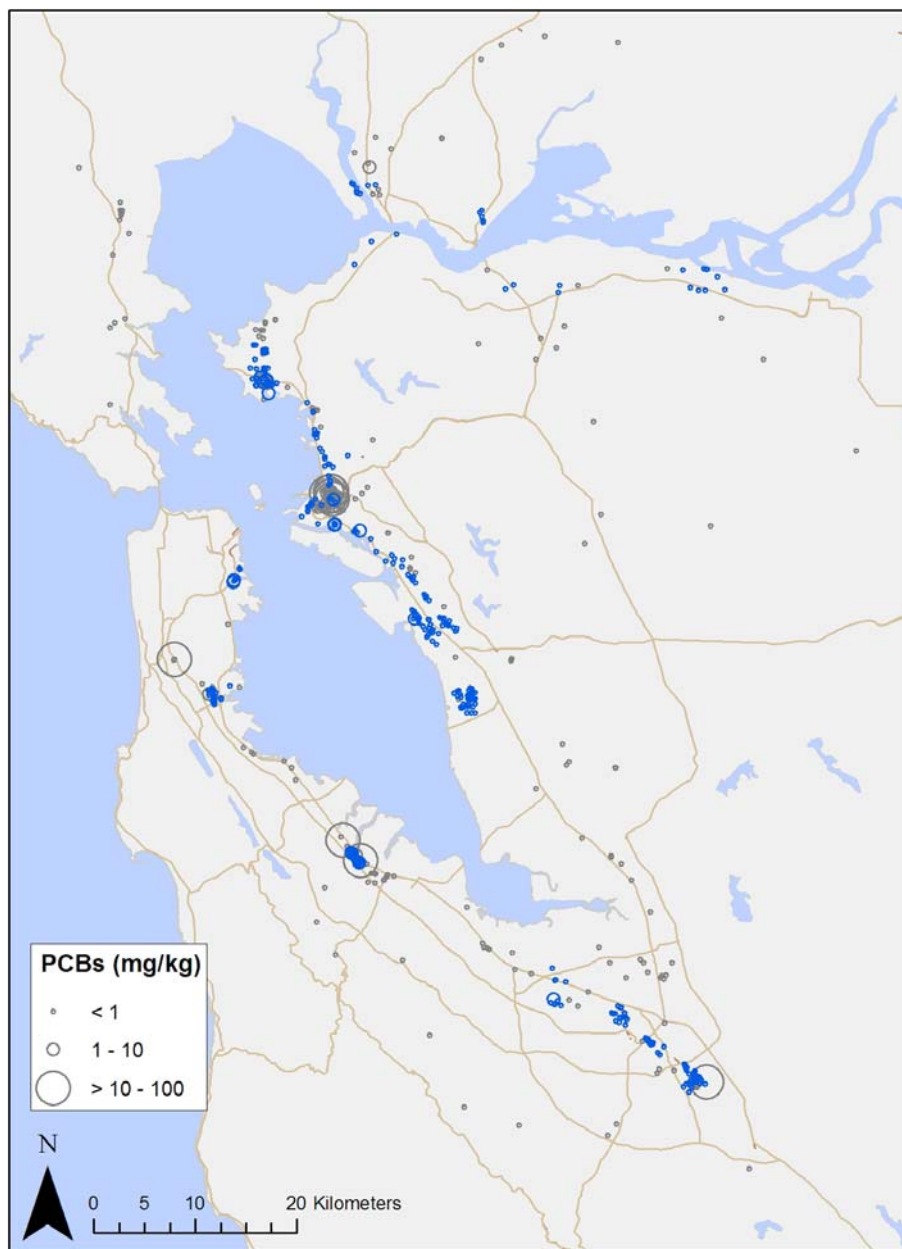


Figure 5. Particulate PCB concentrations sampled in storm collection facilities and streetside soils in the Bay Area in this study (blue symbols) and others (grey)

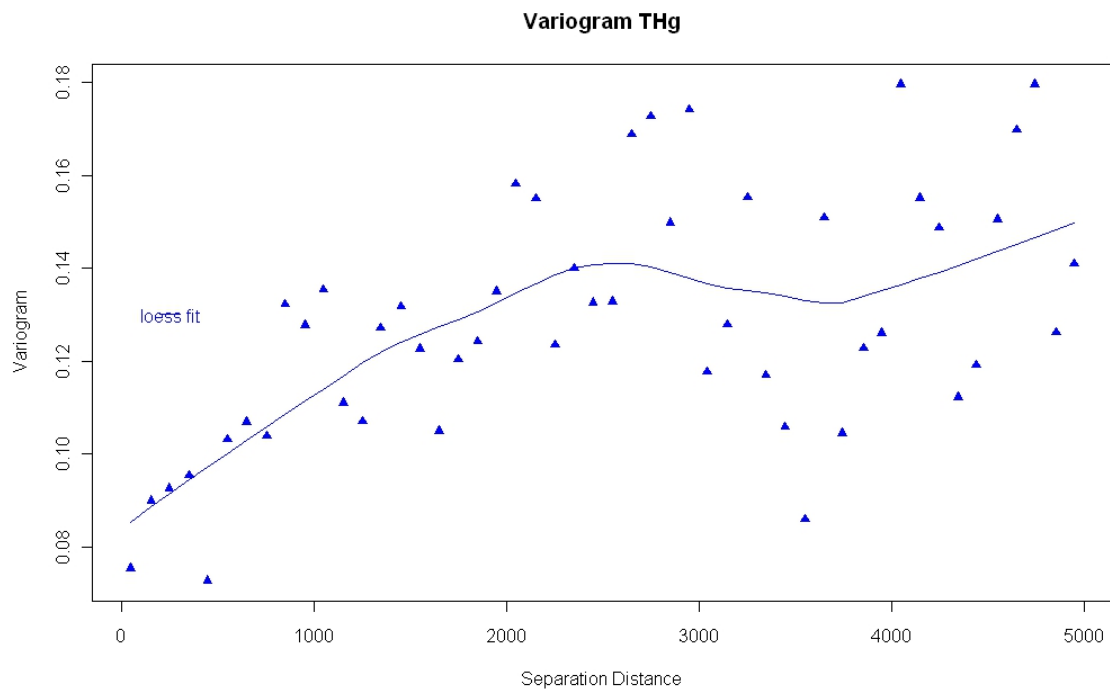


Figure 6. Total Hg variogram based on compiled particulate data collected in soils and sediment of the Bay Area, this study and others

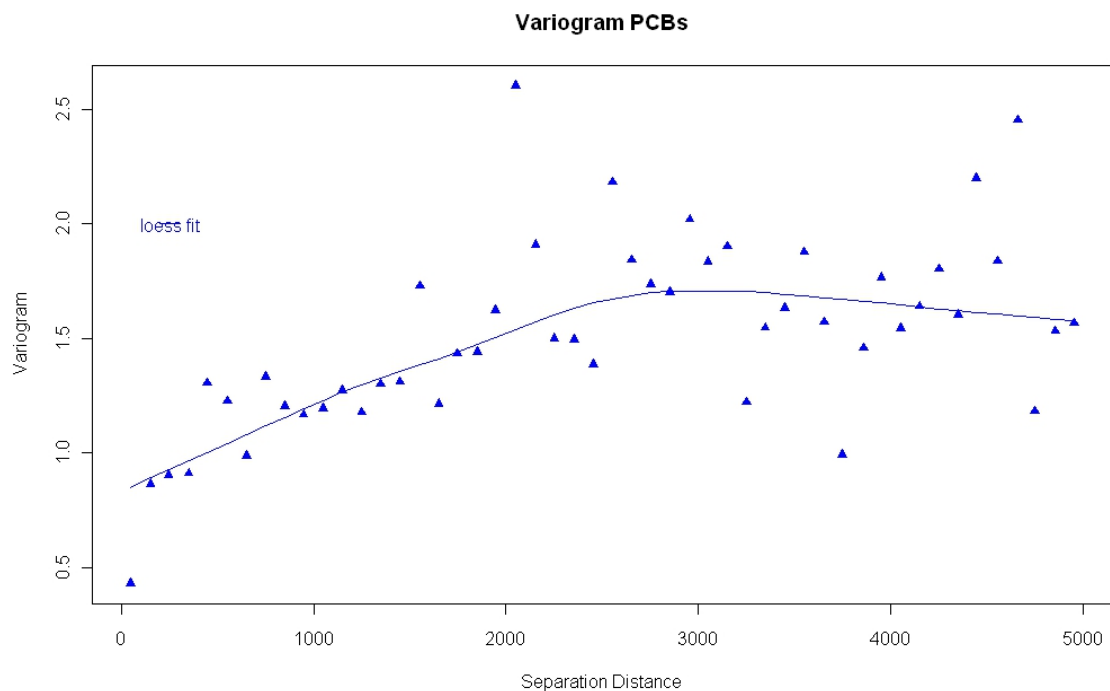


Figure 7. Total PCBs variogram based on compiled particulate data collected in soils and sediment of the Bay Area, this study and others

Another notable characteristic in the spatial distribution of these pollutants is the lack of overlap in locations with high concentrations of Hg with those for PCBs, shown visually in the differing areas with large circles in the bubble plots of Figures 4 and 5. Conversely, low concentrations of Hg are also no assurance of low PCBs; of the 91 sites in the bottom quartile (<0.11 mg/kg) of Hg concentrations sampled in this project, 18 of them are in top quartile of PCB concentrations, similar to the ~23 sites that would be expected if Hg and PCB concentrations were independently randomly distributed. Overlap of locations with high (or low) concentration of these pollutants is not expected on a small scale, as the individual sources for each of these pollutants differ. This lack of similarity in Hg and PCB distributions can also be demonstrated statistically. Because of the preponderance of results below the detection limit for total PCBs (slightly over half non-detects for all congeners), non-parametric comparisons are preferable to parametric comparisons using substitutions. Using the Kendall rank correlation coefficient test for censored data (MINITAB software), the tau b coefficient (for ordinal rankings, with adjustments for ties) was calculated to be 0.16, indicating nearly no correlation between total Hg and PCBs (values of 1.0 and -1.0 represent perfect positive and inverse correlations, 0 indicates no correlation).

Examining sites sampled in each city within the top quartile of reported Hg and PCB concentrations in this study, the most polluted sites are not uniformly distributed for the sampling scheme used in this study, which was heavily biased towards primarily commercial and industrial sites (Table 2). If the most polluted sites were randomly distributed and the sampling schemes were unbiased, we would expect around 25% of sites from each area to be in the top quartile of results. Areas with small numbers of sites might be expected to have highly variable percentages of more polluted (top quartile) sites (e.g. Albany, with 100% and 0% for Hg and PCBs respectively), but some areas with relatively large total numbers of sites have lower than average numbers of top quartile sites (e.g. Hayward).

Table 2. Sites with Top Quartile Hg and PCB concentrations (mg/kg) in sediments and soils sampled in this study by city/area

Areas Sampled	# samples PCB > .10	% with high PCB	# samples Hg > 0.31	% with high Hg	Total #
Albany		0%	2	100%	2
Vallejo	4	44%	6	67%	9
Richmond	15	38%	20	51%	39
Pittsburg		0%	4	44%	9
San Francisco	8	67%	5	42%	12
Benicia		0%	2	40%	5
Port of Oakland	7	47%	6	40%	15
Berkeley	4	31%	5	38%	13
Oakland	12	43%	9	32%	28
San Leandro	6	15%	8	20%	40
South San Francisco	3	20%	3	20%	15
San Jose	2	4%	11	19%	57
Uninc, Contra Costa		0%	1	17%	6
Hayward	3	8%	5	13%	40
San Bruno	5	38%	1	8%	13
San Carlos	15	38%	2	5%	39
Concord		0%		0%	2
El Cerrito		0%		0%	1
Emeryville	2	33%		0%	6
Sunnyvale	4	44%		0%	9

Many of the recent local studies of watershed pollutant distributions (including this one) have implemented biased sampling schemes, focusing on sites near known historical sources or in commercial and industrial areas which might be expected to have higher concentrations of pollutants. However, the first year of sampling (2000) in the joint stormwater agency investigation of pollutant sources (KLI 2002) included a number of sites with other land use types, while the second year (2001) biased sampling to focus on industrial areas. When sites in the top quartile of measured Hg and PCB concentrations from the first year of the KLI study (“KLI 2000”) are considered, a disproportionate majority of them were found in industrial or mixed use areas (Table 3).

Table 3. Sites in Top Quartile of KLI 2000 Sampling by Land Use (KLI 2002)

Sites Sampled in 2000	Total #	# PCB top 25%	# Hg top 25%
Industrial	24	8	11
Mixed	15	3	2
Open	14	0	1
Residential/Commercial	10	4	1

From that work it might be expected that the top quartile, or other statistics of a data set composed of locations primarily in industrial or mixed use areas would tend to have higher pollutant concentrations than a set with mixed locations. However, results were mixed; the top quartiles of PCB and Hg concentrations in the KLI sampling (including many non-industrial locations) for the first year (2000) were 0.107 and 0.24 mg/kg, respectively, very similar to the top quartile for this study (nearly all commercial and industrial sites) of 0.10 and 0.31 mg/kg. Even if the first year of KLI data is reduced to urban sites (i.e. excluding open sites), top quartile concentrations of PCBs and Hg only increase slightly to 0.13 and 0.29 mg/kg respectively, indicating the presence of many commercial and industrial sites with low to moderate concentrations.

Differences in median concentrations were slightly larger, with KLI data in 2000 showing median concentrations for PCBs and Hg of 0.058 and 0.13 mg/kg respectively, and medians for urban sites in that dataset for PCBs and Hg of 0.058 and 0.16 mg/kg. Median PCB and Hg concentrations in this study were <MDL (with a lowest reported value of 0.006) and 0.17, respectively. Because of extensive non-detects (<MDL) in this data set, comparisons of differences are made using non-parametric statistics. Using a Mann-Whitney test for comparing two distributions with censored values using tied ranks for values below the highest reporting limit (MINITAB software, with a macro for censored values (Helsel 2005)), Hg concentrations in this study were not significantly different ($p=0.34$) from those in the KLI 2000 set excluding open space sites, the subset most similar to this study. For PCBs, the same test showed the KLI 2000 urban sites to be significantly higher ($p=0.0002$) than this data set.

Pollutant Fractionation

The goal of this portion of the study was to build our understanding of the characteristics of pollutant distribution in various environmental matrices, in order to provide data to support the selection and design of various institutional and treatment control measures available to counties and municipalities. We examined collected samples of flowing stormwater during precipitation events, and bed sediments from large conveyances during a quiescent period between storms. These samples were analyzed for Hg and PCB concentrations in various size fractions defined by settling time assuming a constant particle density.

Samples selected

Whole water samples were taken during 2007 from Zone 4 Line A (Z4LA), a 100% mixed urban watershed of about 4.5 km² in size situated in Hayward near the Bay margin between Hwy 92 and the Hayward air terminal and extending across the Hwy 880 freeway up to the BART track. Water samples were taken on February 8, 9, and 10, 2007 (N37.64528 W122.13722). Samples from each event at Z4LA were collected into pairs of 4L amber bottles filled with minimal headspace (2 bottles of ~4.5-5L each=9-10L per event). Additional stormwater was collected from a storm drain in Richmond on January 4 (2 events) and January 25 (1 event), 2008, with three 4L bottles (~13-14L) filled each event). The Richmond site is located at the intersection of Hoffman Boulevard and South 8th Street (N37.9234 W122.3620) and is an underground pipe/channel approximately 2 meters in diameter. The sampling location is within the zone of tidal influence, so the highest stage at this location does not necessarily correlate with the period of greatest runoff but care was taken to sampling stormwater that was completely derived from rainfall in the watershed during periods when the pump station just upstream was in operation.

Stormwater samples were collected manually using established clean hands protocols (e.g., USEPA 1996). At Z4LA, samples were taken by inserting an acid-cleaned 1-L Teflon sample bottle into a D-95 depth-integrating sampler and lowered using a B-reel manual winch attached to a USGS Type A crane mounted on a 4-wheel truck. The bottle was filled by passing it evenly through the water column (single vertical transect) aiming to fill the bottle by the time it reached the surface again; if the bottle was less than around $\frac{3}{4}$ full, it was passed through the water column again quickly until mostly full. In the underground channel, a pole mounted DH-81 depth integrating sampler was lowered and raised through the flow until the sample bottle was mostly full. Sample water was decanted into 4L amber glass bottles, while inverting and swirling to minimize residues in the sample bottle. All samples were labeled, placed on ice, and transported to the SFEI for further processing.

Sediments from storm drain inlets and in some cases manholes were collected on March 4, 2010 from four locations previously sampled in this study or previous studies (as indicated): RMD25 (W Cutting Blvd, Richmond), SFO12 (Rankin St, San Francisco), and OAK6 (Prune St, Oakland) from this study, and SMC20 (Industrial Rd, San Carlos (KLI, 2002)). Grab sediment samples were collected by polyethylene scoop, with several grabs mixed together to form a single composite, then placed into four 8 oz glass jars for a total sample volume of about 32 oz. Samples were kept on wet ice while in the field, and then shipped at the end of the day on wet ice to the processing lab (Brooks Rand).

Processing and analytical methods

At the start of this study, sieving methods for separation were considered. However, given reports of various problems that may be encountered in sieving large volume samples (Bonnema, pers. comm.) that would be required for analysis of trace organics, filter contamination issues reported by SCCWRP (Stein pers. comm.), issues associated with hold times (<6 hours) for particle size analysis (Stein and Stenstrom pers comm.; (Kayhanian et al. 2002)) and available lab facilities and equipment, a settling approach was chosen instead for both stormwater and bed sediment fractionation experiments. The settling approach has the advantage of better representing field conditions encountered in various treatment control options where efficacy is at least partly related to settling times.

Stormwater settling separation

The general approach used here for separation of collected stormwaters was akin to an Imhoff settling cone, using 4L sample bottles as settling chambers. Although Imhoff cones are available commercially, they were deemed impractical due to a number of factors: 1) commercially available Imhoff cones are generally ~1L maximum; 2) costs are over ~\$200 each; 3) precleaning by an analytical laboratory or cleaning between samples would require many separation cones; 4) collection of material could be tricky as desired settled material might stick to walls on dispensing

from bottom plug. None of these limitations is individually insurmountable, but in aggregate presented enough obstacles that we opted not to use commercially available Imhoff cones. Agencies that already possess the equipment and process smaller or fewer samples might instead opt for that equipment, as separations using sample bottles also have some limitations (discussed below).

Advantages of the bottle settling method are:

- 1) the simplicity of the process,
- 2) the low cost of materials, allowing,
- 3) precleaned materials prepared for many samples,
- 4) large volumes need for PCB laboratory analysis processed without splitting samples, and
- 5) settling time operationally defined directly mirroring any settling process treatment BMP.

Some limitations of the method are:

- 1) collected particle size is poorly constrained; settled material includes a range of sizes, with small particles near the bottom settling out in the same time required for larger particles from the top,
- 2) this method is difficult to use for separating particles larger than 75 μm because the settling time becomes too short (e.g. 30 seconds for 150 μm particles of 1.7g/ml density) relative to the draining time,
- 3) sample particle density cannot be known *a priori*, so the actual minimum particle size clearing the entire water column within the settling time is not known,
- 4) each discharge disturbs fluid removed from the bottle, so subsequent fractions need to settle the entire period, rather than cumulatively longer (e.g. as one in theory could for an Imhoff cone by discharging particles from the bottom, assuming none stick to the cone edges). For particles smaller than 25 μm the cumulative settling time of taking multiple fractions can thus be very long, and
- 5) remnant fluid is included with the desired settled material, so determining the truly settled material must be made through calculation, e.g. by assuming the remnant water has the same composition of smaller particles as the discharged fraction.

Collected samples were separated as soon after collection as possible (<6 hours) on samples that were cooled (wet ice) to minimize flocculation or sorption of pollutants to the container. The bottle containing the collected sample was inverted three times to resuspend any settled sediment. A modified bottle cap with inlet and outlet tubes replaced the original bottle cap, the original cap placed over the inlet and outlet tubes to prevent draining, and the bottle inverted, and allowed to settle for a predetermined period of time (Figure 8). The cap blocking the (air) inlet and (water) outlet tubes was then removed, discharging the overlying water through the modified cap into a second bottle. Discharge time was about 30 seconds, during which additional settling could occur. However, with the discharge point near the bottom of the bottle, much of the additional settled material would be discharged from the bottle. The discharge was subsequently inverted three times to mix the sample again, the modified cap placed on that bottle, inverted, and settled for a longer period to separate progressively smaller particles. The final overlying water represented particles nominally <25 μm for an assumed density and ideal (spherical) shape for the maximum calculated settling time. The samples were separated into 3 fractions: 1) materials settled out in less than 2 minutes, 2) settled in 2-20 minutes, and 3) not settled by 20 minutes. These correspond to particles of around >75 μm , 75-25 μm , and <25 μm respectively, based on idealized (Stokes) settling velocities in water at 20 degrees C and assumed particle density (specific gravity of 1.7).

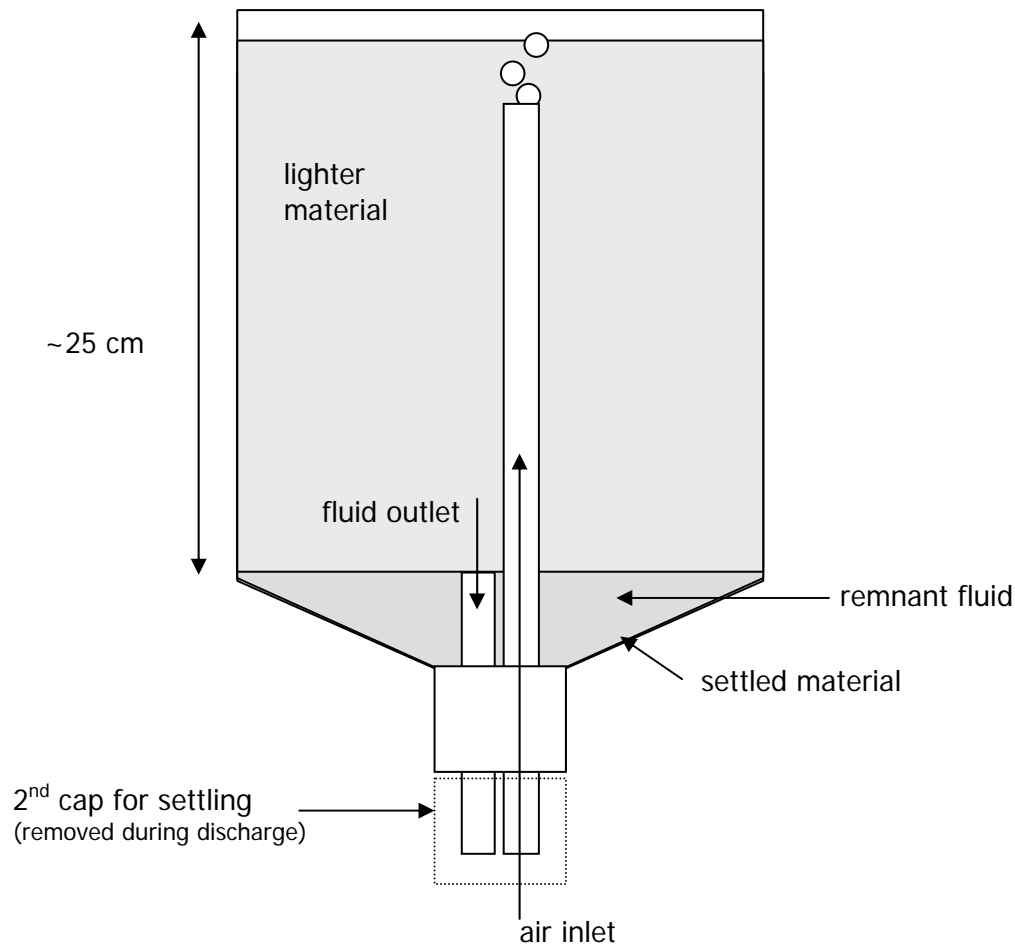


Figure 8. Settling experiment schematic

Stormwater fractions laboratory analyses

After the settling separation, the volumes of the fractions were recorded, and the fractions were inverted three times to homogenize for subsampling into bottles to be sent to the various analytical laboratories. Subsamples for mercury analysis were sent to MLML, and analyzed by a modified EPA Method 1631e (USEPA 2002), i.e. mercury in water by oxidation, purge and trap, and cold vapor atomic fluorescence spectrometry. Small modifications were made by the laboratory in bottle cleaning procedures, sample size, and reagent amounts used. QC samples analyzed with each batch included blanks, replicates, matrix spikes, and reference materials. The detection limit for mercury was 0.2 ng/L, with all field samples reported above that limit. All QC sample results were acceptable, with no mercury detected in lab blanks, and replicates, matrix spikes, and reference materials within the target range ($\pm 25\%$ of their expected values).

Subsampled fractions for PCB analysis were sent to AXYS Analytical of Sydney, BC, Canada, and analyzed by a method equivalent to EPA Method 1668 (USEPA 2008), PCBs in water by HRGC/HRMS. MDLs for individual congeners reported ranged 0.5 to 6 pg/L, with no non-detect results reported. QC samples analyzed included blanks, and blank spike samples as there was insufficient material for replicates or matrix spikes using field samples, and no low level aqueous phase reference materials are available for PCBs. Many congeners were found at trace levels in

blanks, but well below 1/3 of concentrations in field samples, and PCBs in the blank spike were recovered at concentrations within the target ($\pm 35\%$ of their expected values).

Bed sediment separations

The settling separation described here shares many of the same advantages and limitations compared to sieving separations as described previously. Collected bed sediment samples were sent to Brooks Rand for separation via settling. Sediments were first passed through a coarse 2mm mesh sieve to remove large debris. 100 grams (wet weight) of sediment was added to 500 ml ultrapure lab water in a large (500 ml) glass graduated cylinder, placed on a shaker table at room temperature (22 C), and shaken for an hour. The initial height of the sediment and water mixture was 31 cm. After a final vigorous shake, the mixture was allowed to settle for 62 seconds, after which overlying fluid mixture was drawn off by vacuuming into a clean Erlenmeyer flask to a final height of ~2 cm above the settled solids (6-10 cm height total, depending on the sample). Fluid removal took approximately 10 seconds total. The first settled ">75 um" fraction was rinsed twice with 100 mL additions of lab water and allowed to resettle for the same amount of time. The rinses were removed by vacuum suction and stored separately from the initially removed fluid mixture.

The process was repeated with the remaining fluid mixture, after addition of lab water to the same initial (31 cm) height. The second settling time was 9 min 24 sec, yielding a settled "25-75 um" fraction. The liquid was removed in the same manner to a height ~2cm above the settled solids (3-8 cm height total, depending on the sample). Settled solids were again rinsed twice with 100 mL additions of lab water, with longer (9 min and 24 sec) settling time for each rinse. These rinses were also collected and stored separately. The fluid mixture initially removed in the overlying water after settling of the 25-75 um fraction was designated the "<25 um" fraction. The <25 um fraction was placed into analysis containers immediately after collection. The wet >75 um and 25-75 um fractions were homogenized by stirring with a stainless steel spatula and subsampled for distribution to the various analytical labs. The residual rinses were combined, subsampled, dried and weighed to estimate the mass of sediment lost in the rinse. The total volume of rinse liquid was recorded to estimate the potential mass of pollutants lost in the dissolved phase of the rinse. Two blanks were collected using clean DIW. The first blank was pushed through a clean sieve, collected and then put into the column as a sediment in using clean glassware. The blank was vacuumed out of the column into a clean Erlenmeyer flask and collected. The second blank was collected from a DIW column, where 600mL of clean water was added to a column, vacuumed into a clean Erlenmeyer and collected.

This experiment made no attempt to further settle out particle fractions <25 um. Calculated Stokes settling times get exponentially longer for progressively smaller particle sizes. Fine particulate and colloidal material was not easily removed by settling. For the stormwater separations described previously, some fine material settled out during refrigerated storage of samples (for ~1 day) before they were sent to analytical labs, but much of that material was easily resuspended unless great care was taken not to disturb the bottle on removal from the refrigerator. Removing the fine particulate matter from <25 um fraction was similarly difficult for separated bed sediment samples. Brooks Rand chose centrifugation at 3500 RPM for 15 minutes to separate <25 um solids from dissolved or colloidal phase material for their mercury analysis. AXYS instead chose filtration through 1 um glass fiber filters, requiring up to 9 filters (47mm diameter) to treat ~300 mL of suspension. Both separations still left visible cloudiness in suspension, material that would likely not be removable by settling.

Bed sediment fractions laboratory analyses

Subsamples for Hg analysis were kept by Brooks Rand for analysis. The >75 um and 25-75 um fractions were handled as sediment samples. The <25 um fractions were centrifuged at 3500 rpm for 15 min, with the overlying liquids carefully removed for analysis as aqueous samples. The centrifuged <25 um solids were handled as sediment samples. Small subsamples of each fraction

were weighed, dried, and reweighed to estimate total solids content. Sediment samples were analyzed for total Hg by modification of EPA Method 1631E. Samples of ~ 1 g were digested in aqua regia overnight at room temperature to produce an aqueous extract, followed by the usual EPA Method 1631E steps of oxidation, reduction, purge & trap, and measurement by CVAAS. Water samples were analyzed for Hg following the general steps of EPA Method 1631E. Analytical batch QC samples included blanks, blank spikes, certified reference materials, with matrix spikes, and replicates for samples with sufficient material. Samples passed all laboratory internal batch QC checks but have not been further reviewed by project staff for environmental coherence and consistency with previous data and should be considered preliminary

Subsamples for PCB analysis were shipped to AXYS Analytical laboratories. The >75 um and 25-75 um fractions were handled as sediment samples using Soxhlet extraction. The <25 um fraction received at AXYS was separated by vacuum filtration using 1 um nominal pore size glass fiber filters. Filtered material (1-25 um) was extracted by distillation using a Dean-Stark apparatus to remove excess water. Filtrates from the <1 um fraction were handled as aqueous samples, using liquid-liquid extraction. PCBs in extracted samples were analyzed by EPA Method 1668B, with minor lab specific modifications. Laboratory batch QC samples included blanks, blank spikes, and reference materials. Samples passed all laboratory internal batch QC checks but have not been further reviewed by project staff for environmental coherence and consistency with previous data and should be considered preliminary.

Subsamples for particle size distribution analysis were analyzed using laser diffraction (LISST-Portable, Sequoia Scientific) reported in 32 size bins from 1.25 to 250 microns. Results were reported as particle volume concentration in each size bin as uL/L (microliters of solid/liter of suspension), a value proportional to mass in each bin for constant particle density. A total of 12 samples (four locations of three fractions) were analyzed. Fine (<25 um) fractions were subsampled by pipetting 2 mL of sample into a 50-mL centrifuge tube, then filled with milli-Q water to dilute. The medium sized (25-75 um) fractions were subsampled by pipetting 1 mL of sample into a 50-mL centrifuge tubes, then filled with milli-Q water. The coarser (>75um) fractions were subsampled using a teflon-coated spatula and placed in 50-mL centrifuge tubes, then filled with milli-Q water. QA: Triplicate measurements were performed on one of the fine fraction samples. Duplicate measurements were performed on one of the medium fraction samples and one of the coarser fraction samples. Reported particle volumes on duplicates were within 10% of one another in size bins within the range expected for each fraction (i.e. bins <25 um, 25-75 um, >75 um), except for the largest size bin in the >75 um replicate, which had a high RPD of 26%.

Results and discussion

Stormwater fractions

Total volumes and concentrations of Hg and PCBs in the collected fluid samples were measured by the contracted analytical laboratories. Raw masses of Hg and PCBs in collected fractions were calculated as:

$$M_X \text{ (ng)} = V_X \text{ (L)} * C_X \text{ (ng/L)},$$

where M= mass, V=volume, C=concentration, and the subscript X indicates the fraction (*A*, *B*, or *C*) collected. The resulting pollutant masses collected in each of the bottles are not purely the target size fractions derived from the calculated settling times, as there is remnant overlying water in each step which consists of particles from the smaller size fractions. A correction can be applied to reduce the error with some simplifying assumptions.

If we call the raw 2 minute, 20 minute, and >20minute fractions *A*, *B*, and *C* respectively, and use *AT*, *BT*, and *CT* to represent the respective “true” (corrected for carryover) fractions that would be settled in 2, 20, and >20 minutes respectively, then for the true mass of *CT*:

$$M_{CT} = M_C + (V_A + V_B) * C_C$$

The last term adjusts for the masses in the volumes of fractions *A* and *B* which presumably contain particles of size *C*, at the same concentrations ultimately found in fraction *C*. This correction includes a major simplifying assumption that particles of the *C* size class are uniformly distributed in the remnant and overlying water at the time of separation. Although this is not exactly true, additional correction would require knowledge of the actual particle density and size distribution for the sample.

Likewise for the true mass of *BT*, the extra mass in fraction *B* from particles in the *C* size class must be subtracted:

$$M_B - V_B * C_C$$

The particles of target size *B* ending up in the raw fraction *B* are missing the portion left behind in fraction *A*, *i.e.* they are the fraction of the total initial sample volume:

$$(V_B + V_C) / (V_A + V_B + V_C)$$

To get 100% of the M_{BT} , we multiply the portion found in raw fraction *B* by the inverse ratio:

$$M_{BT} = (M_B - V_B * C_C) * (V_A + V_B + V_C) / (V_B + V_C).$$

The true mass of *AT* can then be derived by subtracting the true masses of *BT* and *CT* from the total mass, which by mass balance must equal the sum of the raw masses.

$$M_{AT} = M_A + M_B + M_C - M_{BT} - M_{CT}$$

Alternatively, it can be derived as the raw mass of *a*, subtracting the portions of *B* and *C* in volume *A*:

$$M_{AT} = M_A - V_A * ((M_B + M_C) / (V_B + V_C))$$

In the figures below, fraction *AT* is the mass settled in 2 minutes, *BT* the mass settled in 20 minutes, and fraction *CT* the mass of pollutant remaining suspended and dissolved after 20 minutes. These “true” fractions reported are corrected for carryover, as described above. The initial concentration of the pollutant in each total sample (the sum of fraction masses divided by the sum of volumes) is indicated in the column label (in parentheses).

Samples were taken during storm events in February 2007 during rising and falling stages of 3 separate rain events (Table 4) at Zone 4 Line A and during three events at the Richmond Storm Drain site. However, one of the Richmond samples was damaged after fractionation, so the fractions for that sample could not be characterized. At Zone 4 Line A, suspended sediment concentrations measured in samples not subjected to fractionation procedures ranged between 102-253 mg/L.

PCBs in the material settled within 20 minutes accounted for half or more of the total PCBs in three of the four samples taken. Total PCB concentrations were of a similar magnitude in all samples (ranging 19 to 35 ng/L). Samples were collected on the falling stage for 3 of 4 runoff events, and suspended sediment concentrations were very similar (~250 mg/L for 3 of those events), so the similarity among samples in PCB distribution in the three fractions is not surprising. Also as expected, the sample collected in a period with the lowest energy (75 minutes after the smallest peak flow of the sampled events) had both the lowest concentrations of PCBs (19 ng/L) and the largest proportion in the fraction not settled in 20 minutes. The B fraction of one sample from Richmond (RS-1005) was broken in transit to the lab, so results for only two events are shown. Samples from Richmond showed similar characteristics, with similar concentrations, >30% of PCBs settled out within 2 minutes, and >50% settled within 20 minutes. The high stage sample (RS-1003) showed both higher concentrations and a greater proportion rapidly settling compared to the sample taken during a time with less energetic flow in a falling stage.

In contrast, in collected fractions analyzed for Hg, the fractions settled in 2 and 20 minutes were a very small portion of total Hg in the water. For samples collected during the single Zone 4 Line A event in which both rising and falling stages were sampled (Z4-203 and Z4-204 respectively), slightly more Hg settled within 20 minutes on the rising stage sample. In addition, more particulate Hg settled from the sample taken from the event with the highest stage (Z4-205). The percentage of Hg in the different fractions varies more than for PCBs, although for most samples the easily settled fraction was <20%. Like for PCBs, the first sample (Z4-201) collected at the lowest stage with the lowest energy had both the lowest concentration and the largest proportion in the unsettled fraction. Richmond samples showed similar characteristics, with ~20% of Hg settled within 20 minutes (AT and BT fractions) for both, and Hg concentrations similar to those found in Hayward.

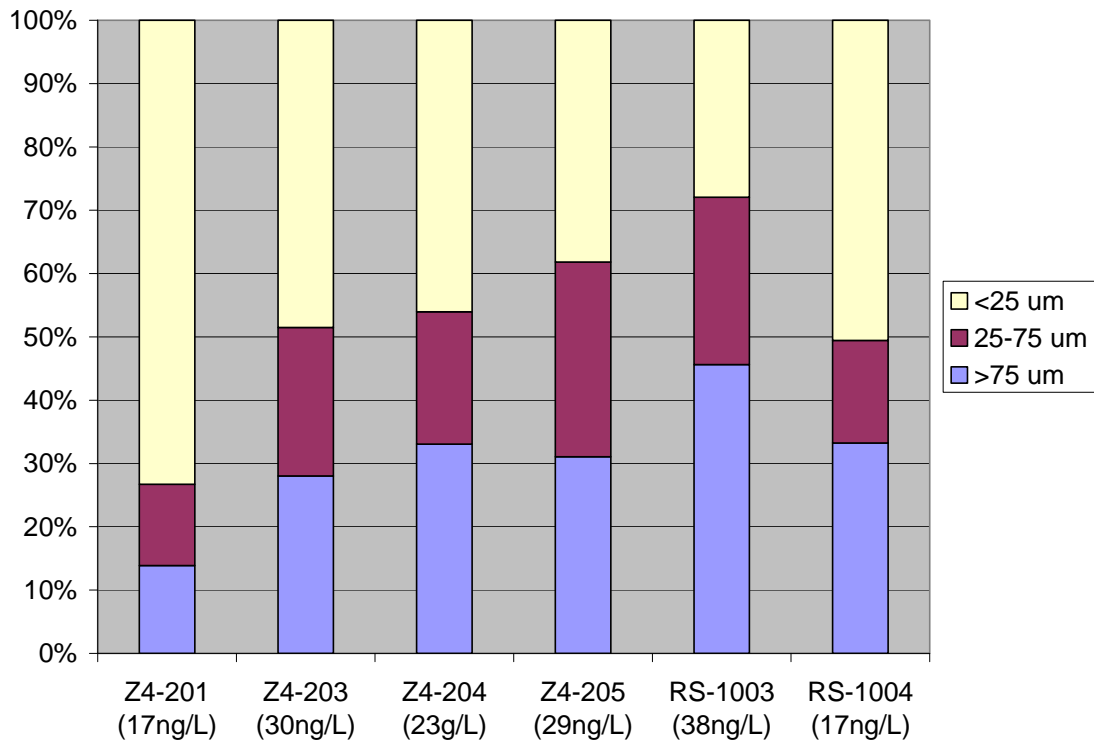


Figure 9. PCBs in Settled Fractions from Runoff at Hayward Zone 4 Line A and Richmond Storm Drain

Table 4. Stormwaters Sampled for Settling Separation

Sample number	Date and time	Stage (ft)	SSC (unfractionated) (mg/L)	Stage character	Relative timing to peak
Z4-201	2/8/2007 15:40	1.04	102	Fall	75 minutes post 1.3 ft peak
Z4-203	2/9/2007 10:25	1.56	253	Rise	15 minutes pre 1.6 ft peak
Z4-204	2/9/2007 10:50	1.47	249	Fall	15 minutes post 1.6 ft peak
Z4-205	2/10/2007 10:20	1.94	242	Fall	25 minutes past 2 ft peak
RS-1003	1/4/2008 09:00	6.56	Not analyzed	High	Peak unknown
RS-1004	1/4/2008 11:15	3.77	Not analyzed	Fall	Peak unknown
RS-1005	1/25/2008 11:30	3.97	Not analyzed	Rise	Peak unknown

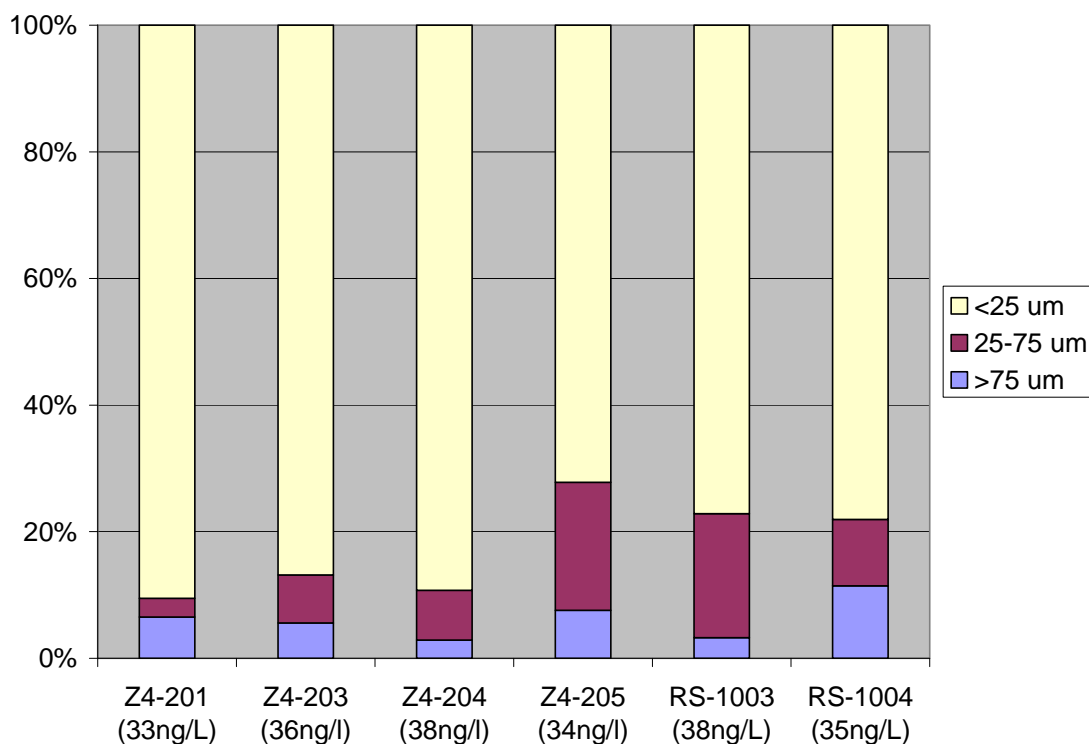


Figure 10. Hg in Settled Fractions from Hayward Zone 4 Line A and Richmond Storm Drain

Bed Sediment Fractions

Figure 11 shows the particle size distributions for the three size fractions for samples collected from the four locations. Particle size distributions generally fall near the expected range based on idealized Stokes settling and assumed particle density of 1.7 g/cm³. Modes (the most abundant bins) for the “>75 um” fractions were between 150-200 um for all the samples. For the “25-75 um” fractions, the modes were between 40-65 um. Also as expected, the “<25 um” fractions were dominantly particles <25 um (modes between 7-13 um).

These particle size distributions suggest that the assumed particle densities used in calculating Stokes setting rates and the appropriate settling time are reasonably close to the actual particle densities; if densities were higher than assumed, particle size distributions (especially in the 25-75 um fraction) would be below or skew to the low side of their expected range, as more small particles than expected would settle out for a given settling time. Conversely, if densities were lighter than assumed, particles would tend to be above or on the high side of their expected range.

Settling rates are expected to be temperature sensitive, as two factors are affected: the density of water increases with decreasing temperature, which can decrease the differential in solid versus liquid density and thus decrease the settling rate, and the viscosity of water increases, which further decreases the expected settling rate. Controls based on settling (whether centrifugal or gravitational) will need to take this into account in the design of systems, particularly for operation in cold weather.

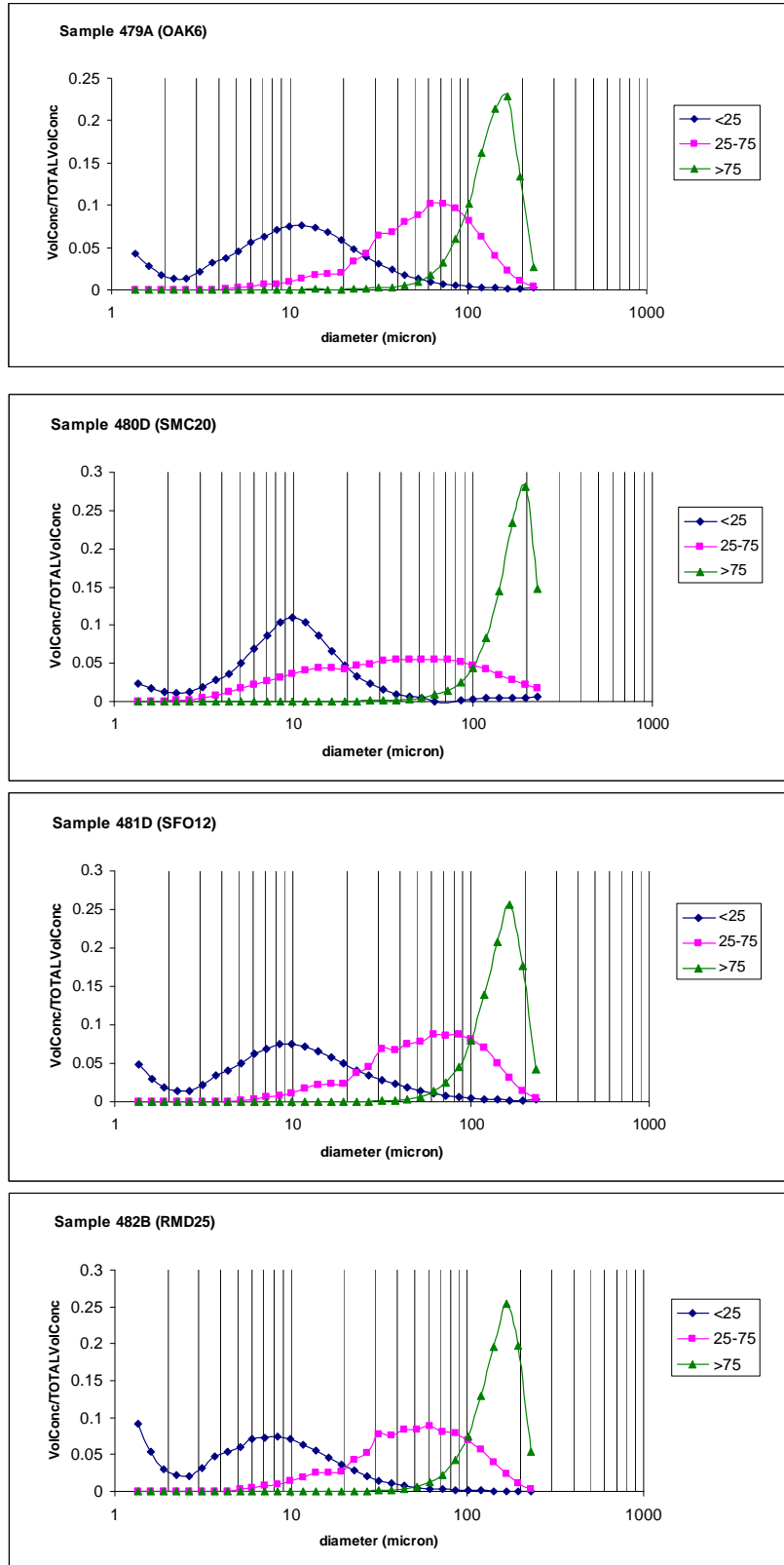


Figure 11. Particle Size Distributions of Separated Bed Sediment Fractions

Hg partitioning

For sediment separation, solids concentration was much higher than in the stormwater settling experiments, so solids mass in each settled fraction was large relative to the portions of finer fractions carried over. Wet solids mass in each fraction is reported in Table 5 (except for the <1um “dissolved” phase, for which only volume (ml) can be reported).

Table 5. Mass in Sediment Fractions (g or ml wet weight).

	OAK6	SMC20	SFO12	RMD25
>75 (g)	95	88	99	95
25-75 (g)	48	64	50	87
<25 (g)	4.5	1.0	3.6	4.7
Diss (ml)	400	400	400	400

Table 6. Hg Concentrations (wet) in Separated Sediment Fractions

	OAK6	SMC20	SFO12	RMD25
>75 (ug/g)	0.10	0.05	0.39	0.28
25-75 (ug/g)	0.11	0.04	0.11	0.28
<25 (ug/g)	0.37	0.19	0.85	0.06
Diss (ug/L)	0.35	0.02	1.04	2.04

Masses of Hg in each fraction were calculated from their respective concentrations (Table 6) and fraction weights. Similar to the stormwater separations, some adjustments need to be applied to masses of Hg measured in each fraction to get their “true” masses. During separation approximately 25 ml of fluid suspension (~5% of the 500 ml fluid used in separations) was left behind with each solid fraction (25-75 um and clay fluid with the >75 um fraction, clay fluid with the 25-75 um fraction). Mass of Hg in each fraction was calculated, then adjusted for carryover. Figure 12 shows the distributions of Hg in the various fractions. Unlike the case for flowing stormwater, only a small fraction (~10% or less) of the total Hg in the sediments remained in suspension or in solution in the <25 um fractions. “Dissolved” concentrations of Hg in these separations ranged up to 2 ug/L, two orders of magnitude higher than the concentrations in the flowing stormwater separations described earlier.

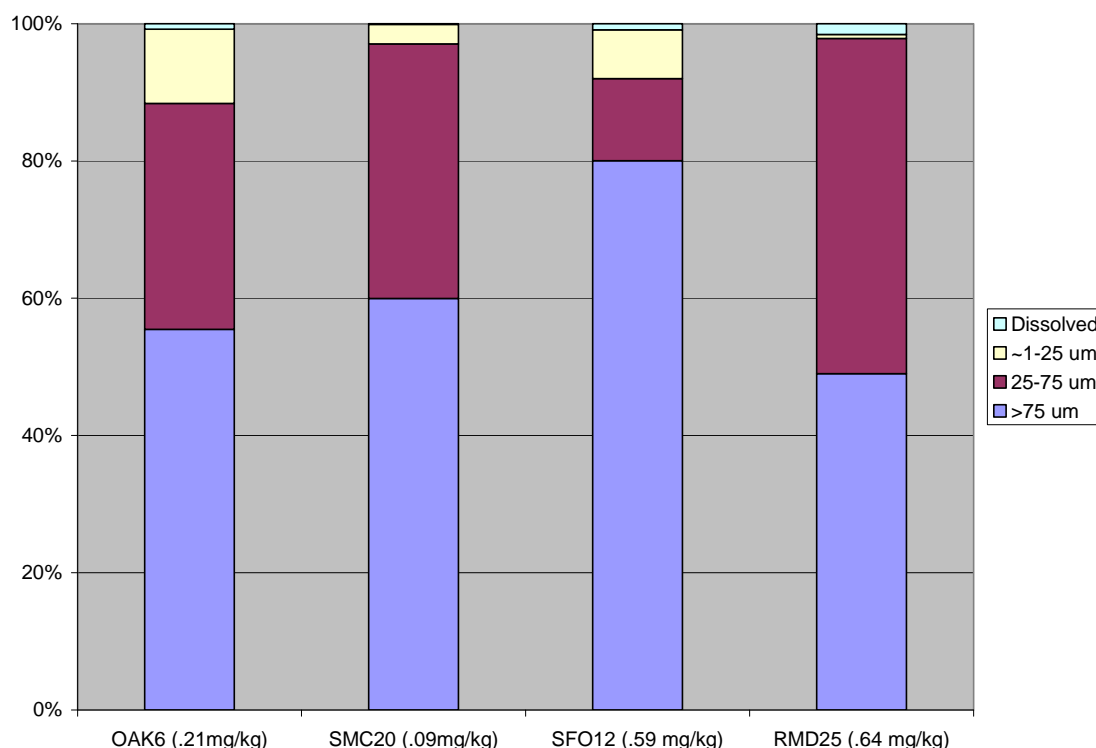


Figure 12. Percentages of Sediment Hg in Settled Fractions

(Hg dry weight bulk concentration in parentheses)

A number of factors likely contribute to the relatively greater partitioning into rapidly settled (>25 um) fractions in this experiment. These samples had accreted in storm drain inlets, remaining even after several moderate to large winter storms had occurred that water year. These areas of accretion thus effectively served as flow-through settling basins (of unknown retention time), so the sediments found would be selectively biased towards material that could settle out more rapidly from storm runoff, whereas the stormwater fractionations described previously represented material that was selectively being mobilized by the sampled storm events.

Another factor that likely plays a part is the high solids concentrations used in the settling experiments. These concentrations are similar to those used in the another work in literature attempting to fractionate large masses of sediment for chemical analysis (Roz et al. 2006). Although the authors there suggest that a settling time of 90 seconds is too short for particle aggregation in a collected sand fraction, they noted that the settling time for silt (15 minutes in that work) was sufficient to allow particle aggregation, especially given solids concentrations much higher than a 0.2% limit previously recommended in the literature (Rose 1953), so aggregation and stripping of smaller particles from solution by differential settling is likely to occur. This effect may be seen in the tail of the particle size distribution for the 25-75 um fraction, with volume concentrations of smaller particles in the fraction approaching up 30% of those in the <25 um fraction, even for particle sizes below 10um. Solids concentrations used here (~160 g/L) are somewhat below those used by Roz et al. (~300 g/L), but are well above concentrations likely to be encountered in routine stormwater flows and thus may not be very representative of typical settling behavior.

Another factor may be equilibrium saturation or kinetic limitation of the dissolved phase Hg content. It is unknown whether the mercury species in solution are in equilibrium; the solubility of elemental mercury in water is much higher at around 60 ug/L (Sanemasa 1975), for liquid mercury in

contact with water. The suspension created here is much more complex, likely containing DOC, various ionic salts, as well as unknown mercury speciation, perhaps with ionic mercury species either free or bound to organic ligands. If the solution were at equilibrium with the solids in suspension, the high concentration of solids would result in relatively little desorption of mercury from the solid phase before equilibrium was reached. Desorption may also be kinetically limited, as the relatively short (1 hour) resuspension time might not be sufficient for Hg in particle interiors to diffuse outward into solution.

PCBs partitioning

Wet weight concentrations of PCBs in separated fractions are shown in Table 7. Concentrations were multiplied by masses for each fraction to estimate masses of PCBs in each size fraction, and corrected for carryover. Figure 13 shows the relative distributions of PCBs in the various size fractions. As was the case for Hg, only a small portion (<30%) of PCBs remained in solution or suspension (<25um), less than the ~50% typically seen in settled stormwater. In higher concentration samples, the percentage dropping out of suspension quickly (>25um) was higher.

Table 7. PCB Concentrations (wet) in Separated Sediment Fractions

	OAK6	SMC20	SFO12	RMD25
>75 (ug/g)	0.06	183	0.22	1.8
25-75 (ug/g)	0.04	53	0.02	0.31
<25 (ug/g)	0.56	2069	1.8	8.6
Diss (ug/L)	0.0005	0.03	0.0005	0.001

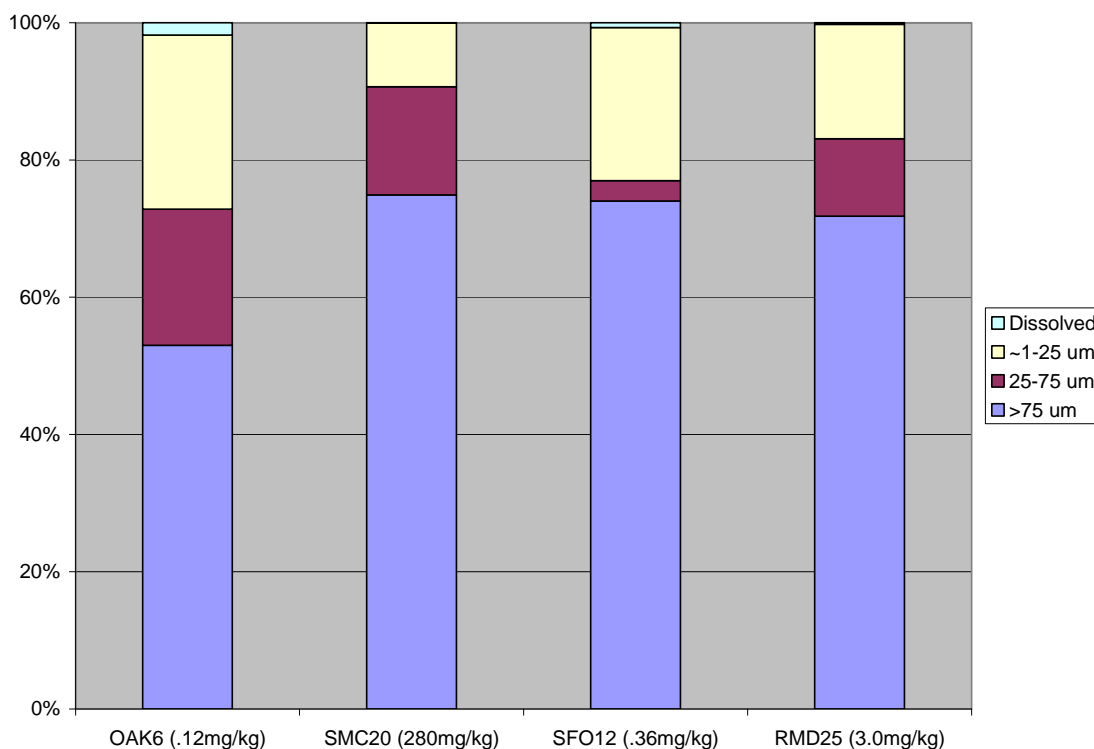


Figure 13. Percentages of Sediment PCBs in Settled Fractions
(PCB dry weight bulk concentration in parentheses)

Implications for Future Work and Management

The work presented here lays the groundwork and indicates directions for future investigation and possible management actions to reduce pollutant loads in stormwater. It also highlights some of the challenges that will be encountered, which may require adjustments in strategy and or expectations. Specific questions that we may begin to address with the information collected here are presented below:

Implications of pollutant distributions

Through a combination of previous work on characterizing pollutant distributions in local watersheds and this work, a number of characteristics are apparent:

1. Pollutant concentrations are highly patchy, even at moderate to small spatial (sub-kilometer) and temporal (~annual) scales. This patchiness reflects the episodic nature of many release (e.g. accidental spills) and transport (e.g. storms) events and processes.
2. Concentrations at sites within 3 km of one another exhibit spatial autocorrelation, i.e. show similarities in concentration, which may be due to similarities in land use, activities, or transport of shared pollutant sources.
3. Individual sites and patches most contaminated with PCBs are often not those with high Hg. This is logical given the different use histories and original sources of the substances.

Considered together, these results reiterate characteristics that are perhaps obvious but worth repeating. Proximity to expected areas of pollutant presence (i.e. areas of industrial usage or disposal) is likely a necessary factor for tracking and locating areas of generally greater soil pollution with PCBs and Hg. However, this factor alone is usually not a sufficient condition for finding high pollutant concentrations within the industrial landscape in the near-field environment (scales around a kilometer or less) at individual sites. The latter likely depends as much on site specific conditions and operations as on the total quantity of pollutants generated or handled in the area. Differences in pollutant concentrations among seemingly similar sites or areas however promises hope that the goals of load reductions in the municipal regional stormwater NPDES permit (MRP) Order No. R2-2009-0074 (SFBRWQCB 2009) can be achieved through management of site specific conditions and operations. The other side of this coin however is that finding additional high concentration locations will not be easy; documentation on current and historical land uses will point to many potential sites that are already relatively clean and unremarkable (false positives).

The requirements described by the MRP include pilot study effort to locate, abate or treat PCB and Hg contamination in urban areas of the Bay Area. The patchy distribution of the sites most polluted by Hg and PCBs suggests that there are relatively few sites that have very high concentrations of both. If we consider only sites in the top 10th percentile for both Hg and PCB concentrations, the combined list of >700 watershed sites reported in compiled studies from the last decade, only 12 sites qualify (Table 8). However, if we loosen the criteria to include the top quartile for each pollutant, the list expands to 55 sites. Using the compiled list of available data, adjusting criteria to include more or fewer sites, perhaps selecting by individual jurisdictions, should provide a few sites that have higher than average concentrations. These sites may be best suited for actions seeking to reduce multiple pollutants together (i.e. as opposed to finding and abating specific sources for Hg or PCBs), and should provide locations where quantitative measurements of the effectiveness of different control measures might be obtained.

Although there likely are additional high concentration locations to be found in the watersheds, the dataset here represents a good list from which to choose sites for testing future management activities. For selecting sites to abate specific sources, lists of individual sites with the highest pollutant concentrations are a good starting point. Table 8 also includes individual locations in the top 10th percentile of Hg and PCBs measured in the combined studies. For the most part, sites

are either in the top 10th percentile for one contaminant or the other, with only a small number elevated in both.

Table 8. Sites with Top 10th Percentile Concentrations of Hg, PCBs, or Both (from combined datasets used in Figures 4 & 5)

SITE_NAME	TOP10	LATITUDE	LONGITUDE	AUTHOR_YEAR	PCBSMGKG	HGMGKG
HWD08	Hg	37.64664	-122.13564	This study.	<MDL	12.54
SJO46	Hg	37.30898	-121.85463	This study.	<MDL	6.23
OAK6	Hg	37.73723	-122.17966	This study.	0.54	4.85
SanLeandroCk	Hg	37.72700	-122.15700	Salop et al., 2002b	0.47	4.29
SCV012	Hg	37.32011	-121.88906	KLI & EOA, 2002	0.12	4.26
PORT10	Hg	37.80893	-122.31233	This study.	0.03	3.9
HWD04	Hg	37.65281	-122.13822	This study.	<MDL	3.31
SJO01	Hg	37.37516	-121.95028	This study.	<MDL	3.26
SCV034	Hg	37.36203	-121.90100	KLI & EOA, 2002	0.14	3.04
Decoto-BART	Hg	37.58900	-122.01600	Salop et al., 2002b	0.12	2.7
SJO35	Hg	37.31236	-121.87038	This study.	<MDL	2.15
CerritoCk	Hg	37.89800	-122.30600	Salop et al., 2002b	0.3	1.99
CordonicesCk	Hg	37.88300	-122.30000	Salop et al., 2002b	0.05	1.92
SMC025 (FR)	Hg	37.70665	-122.39812	KLI & EOA, 2002	0.24	1.91
SCV031	Hg	37.31387	-121.86013	KLI & EOA, 2002	0.05	1.9
VFC005	Hg	38.09460	-122.24187	KLI & EOA, 2002	0.06	1.86
SMC025	Hg	37.70665	-122.39812	KLI & EOA, 2002	0.14	1.73
OAK33	Hg	37.84819	-122.28519	This study.	0.78	1.72
EP1 (24th & Wood)	Hg	37.82025	-122.29226	Salop et al., 2002a	0.23	1.58
VLJ1	Hg	38.09832	-122.25330	This study.	<MDL	1.42
HWD21	Hg	37.63323	-122.12354	This study.	<MDL	1.35
SSO03	Hg	37.65189	-122.39436	This study.	<MDL	1.24
OAK15	Hg	37.76838	-122.21407	This study.	<MDL	1.22
GE-1	Hg	37.82500	-122.25154	Salop et al., 2002a	0.31	1.21
SCV006	Hg	37.37017	-121.94653	KLI & EOA, 2002	0.06	1.18
VLJ2	Hg	38.09907	-122.24509	This study.	0.02	1.14
BRK16	Hg	37.88056	-122.30634	This study.	<MDL	1.11
RMD31	Hg	37.91958	-122.36020	This study.	0.33	1.05
EP1 (26th & Poplar)	Hg	37.81943	-122.28596	Salop et al., 2002a	0.7	1.02
SJO34	Hg	37.30618	-121.87856	This study.	<MDL	1.01
PIT3	Hg	38.03021	-121.86983	This study.	<MDL	0.98
SLO06	Hg	37.72287	-122.19298	This study.	<MDL	0.96
EP2-8	Hg	37.82129	-122.27845	Salop et al., 2002a	0.26	0.95
EttieStPS	Hg	37.82600	-122.28900	Salop et al., 2002b	0.76	0.94
VLJ9	Hg	38.09927	-122.27029	This study.	0.74	0.94
EP1 (32nd & Hannah)	Hg	37.82347	-122.28683	Salop et al., 2002a	0.98	0.88
RMD03	Hg	37.95070	-122.36341	This study.	<MDL	0.86
UCC3	Hg	38.04856	-122.24789	This study.	<MDL	0.86
SCV028	Hg	37.34572	-121.92558	KLI & EOA, 2002	0.17	0.8
RMD24	Hg	37.92517	-122.37341	This study.	0.82	0.78
SausalCk	Hg	37.79100	-122.22200	Salop et al., 2002b	0.04	0.78
SCA36	Hg	37.49967	-122.24462	This study.	0.3	0.77
CordonicesCk	Hg	37.88300	-122.30000	Salop et al., 2002b	0.03	0.76

SITE_NAME	TOP10	LATITUDE	LONGITUDE	AUTHOR_YEAR	PCBSMGKG	HGMGKG
SJO14	Hg	37.35945	-121.94474	This study.	<MDL	0.76
PORT4	Hg/PCB	37.79710	-122.28175	This study.	2.12	3.04
SMC020	Hg/PCB	37.51757	-122.26382	KLI & EOA, 2002	20.29	1.84
RMD28	Hg/PCB	37.92400	-122.36206	This study.	1.98	1.39
SMC024	Hg/PCB	37.67403	-122.45702	EOA,2004	16.81	1.31
SLO02	Hg/PCB	37.71563	-122.18961	This study.	1.27	1.19
RMD25	Hg/PCB	37.92534	-122.36906	This study.	1.24	1.12
SCV001	Hg/PCB	37.31033	-121.85278	KLI & EOA, 2002	26.75	1.08
PORT5	Hg/PCB	37.79724	-122.28143	This study.	7.65	1.03
CCC032	Hg/PCB	37.92538	-122.36910	KLI & EOA, 2002	1.95	0.95
SMC021	Hg/PCB	37.49868	-122.24592	KLI & EOA, 2002	1.22	0.92
Ettie St PS	Hg/PCB	37.82600	-122.28900	Gunther et al, 2001.	3.26	0.8
RMD27	Hg/PCB	37.92121	-122.36476	This study.	1.19	0.74
ETT122	PCB	37.82533	-122.29100	Kleinfelder Inc., 2006	93.41	-
ETT66	PCB	37.82633	-122.28633	Kleinfelder Inc., 2005	31.33	-
ETT56 South	PCB	37.82217	-122.28633	Kleinfelder Inc., 2006	17.73	-
ETT84b	PCB	37.82000	-122.28483	Kleinfelder Inc., 2006	14.73	-
SMC-047	PCB	37.50010	-122.24380	STOPPP, 2003.	11.52	-
ETT58	PCB	37.82283	-122.28650	Kleinfelder Inc., 2005	11.12	-
SMC-047 (FR)	PCB	37.50010	-122.24380	STOPPP, 2003.	10.66	-
ETT63-64-65	PCB	37.82633	-122.28667	Kleinfelder Inc., 2006	10.62	-
SCV046	PCB	37.31115	-121.86393	San Jose & EOA,2003	9.2	-
ETT84	PCB	37.82017	-122.28733	Kleinfelder Inc., 2006	8.21	-
ETT64-65	PCB	37.82633	-122.28667	Kleinfelder Inc., 2005	7.35	-
SMC-023	PCB	37.50483	-122.24915	STOPPP, 2003.	6.19	-
ETT38	PCB	37.82217	-122.28183	Kleinfelder Inc., 2006	6.08	-
SCV046 (FR)	PCB	37.31115	-121.86393	San Jose & EOA,2003	5.95	-
ETT5	PCB	37.81167	-122.28833	Kleinfelder Inc., 2006	5.7	-
SCV059	PCB	37.31032	-121.86520	San Jose & EOA,2003	5.35	-
ETT2	PCB	37.81217	-122.30050	Kleinfelder Inc., 2005	3.81	-
ETT85	PCB	37.82067	-122.28567	Kleinfelder Inc., 2005	3.74	-
ETT111	PCB	37.82267	-122.28433	Kleinfelder Inc., 2006	3.7	-
ETT85	PCB	37.82067	-122.28567	Kleinfelder Inc., 2006	3.63	-
Site I	PCB	37.92280	-122.36590	EOA, 2007	2.79	-
SMC-040	PCB	37.64435	-122.41720	EOA,2002	2.72	-
ETT8	PCB	37.81433	-122.29250	Kleinfelder Inc., 2005	2.51	-
Site O	PCB	37.92330	-122.36720	EOA, 2007	2.39	-
ETT56	PCB	37.82217	-122.28633	Kleinfelder Inc., 2005	2.38	-
ETT84b	PCB	37.82000	-122.28483	Kleinfelder Inc., 2005	2.22	-
SCV058	PCB	37.31032	-121.86520	San Jose & EOA,2003	2.05	-
CCC034 (2002)	PCB	37.92528	-122.36827	EOA, 2007	2.05	-
ETT56	PCB	37.82217	-122.28633	Kleinfelder Inc., 2005	2.05	-
Site N	PCB	37.92310	-122.36220	EOA, 2007	1.99	-
ETT8	PCB	37.81433	-122.29250	Kleinfelder Inc., 2006	1.95	-
CCC032 - Comp (2001)	PCB	37.92120	-122.36006	EOA, 2007	1.88	-
Site M	PCB	37.92400	-122.36340	EOA, 2007	1.84	-
SMC-021	PCB	37.49868	-122.24592	STOPPP, 2003.	1.82	-

SITE_NAME	TOP10	LATITUDE	LONGITUDE	AUTHOR_YEAR	PCBSMGKG	HGMGKG
ETT84c	PCB	37.82150	-122.28567	Kleinfelder Inc., 2006	1.78	-
ETT50	PCB	37.82540	-122.28865	Kleinfelder Inc., 2006	1.75	-
ETT2	PCB	37.81217	-122.30050	Kleinfelder Inc., 2006	1.66	-
ETT63	PCB	37.82600	-122.28650	Kleinfelder Inc., 2005	1.51	-
CCC034 (2005)	PCB	37.92528	-122.36827	EOA, 2007	1.4	-
ETT57	PCB	37.82150	-122.28617	Kleinfelder Inc., 2005	1.29	-
ETT122	PCB	37.82533	-122.29100	Kleinfelder Inc., 2005	1.22	-
SCV033 (2002)	PCB	37.30902	-121.86680	San Jose & EOA, 2003	1.22	-
ETT38	PCB	37.82217	-122.28183	Kleinfelder Inc., 2005	1.14	-
CCC031 - Comp (2001)	PCB	37.92523	-122.36896	EOA, 2007	1.12	-

Even if concentrated true sources are not found, in areas with higher concentrations, redevelopment or various management actions can be considered, including on-site operational improvements, institutional controls such as pollution prevention, education and out reach, optimized street sweeping and collection system maintenance, or diversion and treatment of runoff from the whole industrial area. When more contaminated locations are found, a tier 2 sampling design (like the Ettie Street example) can be used to track, clean up and abate a source and remove a relatively large mass more quickly than downstream or regional controls.

For evaluating institutional controls applied beyond individual sites such as street washing and sweeping, diversion, and treatment further downstream, examining aggregate concentrations over manageable areas may be more appropriate. The combined database of sites used in analyzing spatial variograms described earlier was used to identify 3 km (1.5 km radius) patches of elevated Hg and PCB concentrations. General areas of higher average concentrations were determined through an ArcGIS Spatial Analyst tool "Point Statistics" that takes values over a moving neighborhood using a set radius of influence for each reported point. The tool was set to 1.5 km radius neighborhoods, deriving the mean concentration value of all points within the neighborhood. The output is a raster map symbolized to reflect the gradient of low to high average concentration values, with maps for Hg and PCBs shown in Figure 14. Informed by the raster maps of mean concentrations, approximate centroids of areas with moderate to elevated average concentrations from two or more points were assigned visually, and the average of concentrations for all sites within a 1.5 km buffer of those centroids were derived. The locations of those centroids with 2 or more sites in the area and associated average Hg and PCB concentrations are listed in descending order in Tables 9 and 10, for the top 15 patches of each pollutant.

These centroids do not reflect any particular sampled point, and because they were independently assigned visually for each pollutant on different maps, centroids for Hg and PCBs located near one another may essentially represent the same underlying group of sites. The exact coordinates of the centroids have no special meaning other than being points near the middle of groups of sites with moderate to high combined average concentrations. These are possible areas to consider pilot level studies of institutional controls; the size and shape of areas where controls are applied will likely differ due to jurisdictional and practical considerations.

Given the spatially and temporally variable distribution of contaminants, control effectiveness measured at the outlet end of control measures likely needs to be taken synoptically with measures of input, integrated over time. This can be logistically challenging, analytically expensive, and results statistically uncertain, so evaluation of controls employing removal techniques is best done measuring the removed material where possible, rather than by difference before and

after the control. In some cases, this opportunity does not exist, e.g. in improved training and operating procedures, where the result is not pollutants captured but rather pollutants not released. Benefits of control actions are most easily measured where moderate to high concentrations are repeatedly found; area averages such as those in Tables 9 and 10 can help determine suitable locations for testing meso-scale control actions.

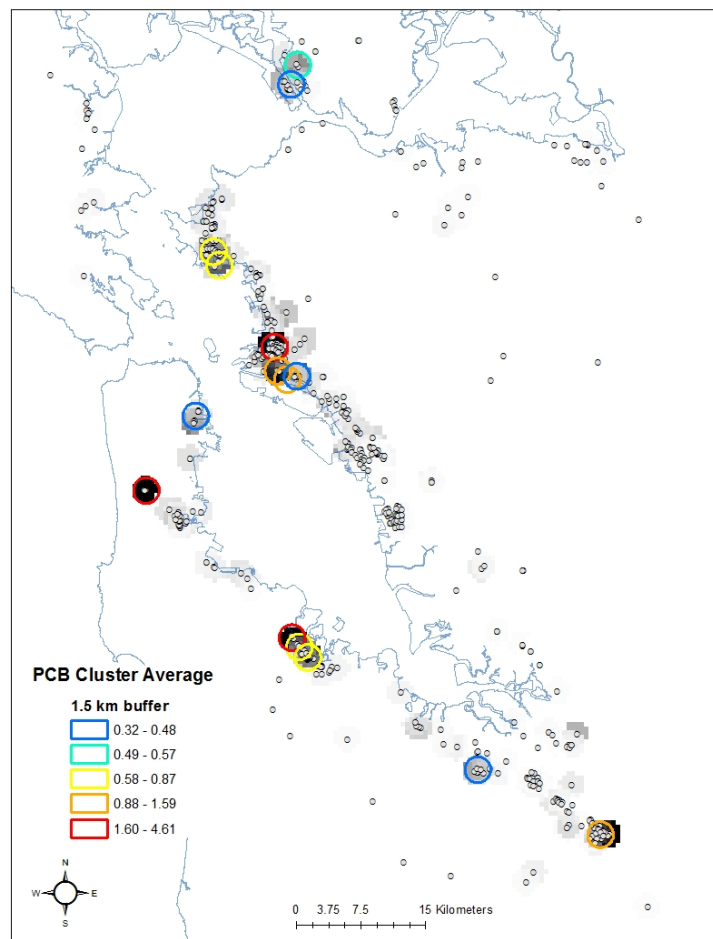
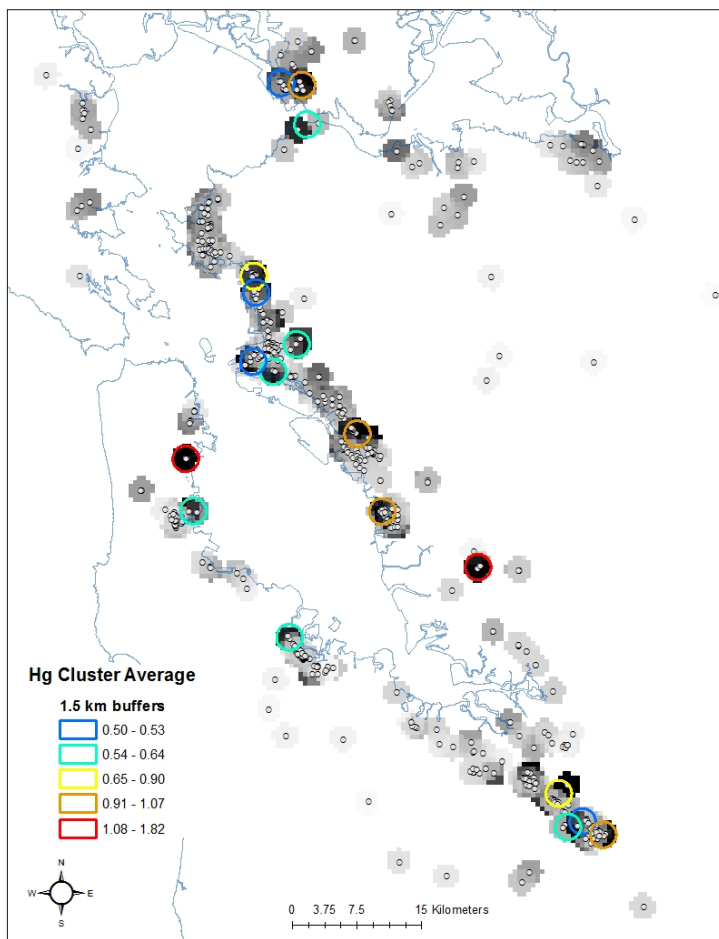


Figure 14. Maps of Averaged Hg and PCB Concentrations (mg/kg)

Table 9. Patches with Highest Average Hg (combined data, this study and others)

Patches are 1.5 km radius circular areas over which site results are averaged

# Sites	Avg_Hg mg/kg	Min_Hg mg/kg	Max_Hg mg/kg	Centroid Y	Centroid X	Patch description (centroid nearest cross-streets)
2	1.82	1.73	1.91	37.70661	-122.39821	Beatty Ave & Hwy 101, San Francisco
7	1.48	0.15	4.85	37.73134	-122.17232	Moorpark and Russet, Oakland
2	1.45	0.20	2.70	37.59104	-122.01551	11th St & Decoto Rd, Union City
5	1.06	0.20	4.26	37.31892	-121.90149	Gregory & Helen, San Jose
5	1.02	0.33	1.86	38.09549	-122.24138	Curtola Pkwy & Solano Ave, Vallejo
7	0.85	ND	3.04	37.79688	-122.28220	2nd St & Castro, Oakland
2	0.80	0.35	1.24	37.65196	-122.38859	E Grand Ave & Grandview Dr South SF
26	0.78	0.08	12.54	37.65006	-122.14030	Cabot Blvd & W Winton Ave, Hayward
6	0.70	0.18	1.99	37.89674	-122.30695	Pierce St & Central Ave, Albany CA
4	0.67	0.15	1.20	37.82512	-122.25132	Glen Ave & Piedmont Ave, Oakland
9	0.56	0.10	1.92	37.87953	-122.30433	4th St & Gilman, Berkeley
12	0.54	0.10	4.26	37.32451	-121.88231	1st St & Union, San Jose
2	0.54	0.22	0.86	38.04882	-122.24999	B St & San Pablo Ave, Rodeo
8	0.51	0.08	1.42	38.09787	-122.26901	9th St & Nimitz Ave, Vallejo
6	0.46	0.05	1.84	37.51956	-122.26362	Shoreway Rd & Cormorant Dr, Belmont

Table 10. Patches with Highest Average PCBs (combined data, this study and others)

Patches are 1.5 km radius circular areas over which site results are averaged

# Sites	Avg_PCB mg/kg	Min_PCB mg/kg	Max_PCB mg/kg	Centroid Y	Centroid X	Patch description (centroid nearest cross-streets)
6	3.45	ND	20.29	37.51921	-122.26557	Quarry Rd & Industrial Blvd, San Carlos
5	3.37	0.00	16.81	37.67370	-122.45541	El Camino Real & Collins Ave, Colma
99	2.70	ND	93.41	37.82235	-122.28555	Helen St & Peralta St, Oakland
7	2.12	0.24	7.65	37.79749	-122.28152	ML King Jr Way & 1st St, Oakland
9	1.74	ND	7.65	37.78856	-122.26918	Embarcadero Way & Oak St, Oakland
40	1.37	ND	26.75	37.31046	-121.86425	Leo Ave & S 7th St, San Jose
42	0.89	ND	20.29	37.50946	-122.25612	Montgomery St & Industrial Rd, San Carlos
49	0.86	ND	11.52	37.49851	-122.24505	Washington St & Bayport Ave, San Carlos
2	0.80	0.35	1.26	38.11663	-122.25213	Michigan St & Couch St, Vallejo
54	0.74	ND	2.79	37.92235	-122.36499	S 4th St & Cutting Blvd, Richmond
14	0.65	ND	2.26	37.90822	-122.35754	S Marina Way & Hall Ave, Richmond
12	0.44	0.03	1.16	37.75115	-122.38986	26th St & Minnesota St, San Francisco
8	0.41	ND	1.37	37.37960	-122.02375	E California Ave & Morse Ave, Sunnyvale
4	0.36	ND	1.27	37.79185	-122.25654	E 8th St & 7th Ave, Oakland
10	0.28	ND	0.92	38.09641	-122.26086	Mare Island Way & Maine St, Vallejo

Implications of partitioning separations

The results of the partitioning experiments for stormwater and bed sediment samples highlight some differences in Hg and PCB characteristics that will lead to differences in their environmental mobility and ease of removal. Summaries of settling removal efficiencies, the fractions of Hg and PCBs that are very quickly (<2 minutes at 20 C) and quickly (<20 minutes) settled, are shown for stormwater (Table 11) and bed sediments (Table 12).

Table 11. Hg and PCB Stormwater Settling Removal Efficiencies Summary

	min	max	average
Hg			
<2 min	3%	12%	7%
<20 min	10%	28%	17%
PCB			
<2 min	14%	46%	31%
<20 min	27%	72%	53%

Table 12. Hg Sediment Settling Removal Efficiencies Summary

	min	max	average
Hg			
<2 min	49%	80%	61%
<20 min	89%	99%	95%
PCB			
<2 min	53%	75%	68%
<20 min	73%	91%	81%

1. For PCBs in stormwater, settling times on the order of 2 minutes appear sufficient to remove almost a quarter of the total mass. Settling times of 20 minutes removed about half the PCBs on average. In contrast, for Hg, even after 20 min, over 70% of Hg typically remains in solution or suspension
2. A larger fraction of pollutants in bed sediments settles out quickly. These represent pollutants that would be mobilized in high energy high flow events, versus low or moderate flow events sampled in the stormwater separations. PCBs drop out of resuspended sediments at a similar rate as Hg, with over 60% removal in 2 minutes, and average 80% or more removal in 20 minutes or less.

It was expected that pollutant fractionation in bed sediments from storm drain inlets would be even more dominantly in the quickly settled (>25 um) solid fractions, given that the sampled sediments represent a fraction that is already selectively left behind from previous storm flows. Although these sediments are likely to move significantly primarily during larger flow events, given that potential, and the possibility of continued dissolution and desorption of pollutants during lower flow periods, removal of these sediments prior to further mobilization where possible may help ensure that they do not disperse more widely into the environment.

Removal of moderate to large particulate matter in flowing stormwater in many cases appears to be capable of getting us ~20% removal of Hg and ~50% removal of PCBs: around halfway to the load reduction targets in the TMDLs of 50% for Hg and 95% for PCBs. However, given the slow rate of settling and difficulty in removing the finest particulate matter by filtration in the stormwater and bed sediment separation experiments, the load reduction targets may be difficult

to achieve through only flow through removal technologies (aside from end-of-pipe treatment on the scale of a wastewater treatment plants). Achieving the remaining needed reductions will be more challenging, requiring a combination of various available management tools, focusing especially on areas with higher concentrations where the expenditure and effort for additional removal will result in proportionally larger load reductions. A selective approach prioritizing implementation in areas with higher concentrations may also have the added benefit of providing greater improvements in the ambient environment of areas currently most impacted by high concentrations of these pollutants.

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Appendix

Table A-1. Concentration Ranges of Hg and PCBs found in soils and sediments collected in this study during 2007 and 2008

SiteCode	SampleDate	Latitude	Longitude	Mercury (mg/kg)	PCBs (mg/kg)
ABY01	2007/6/20 16:05	37.89644	-122.30905	0.36	<MDL
ABY02	2007/6/20 0:00	37.89597	-122.30885	0.73	<MDL
BEN1	2008/9/11 14:10	38.07833	-122.12479	0.10	<MDL
BEN2	2008/9/11 14:05	38.07624	-122.12666	0.23	<MDL
BEN3	2008/9/11 13:55	38.07301	-122.12476	0.21	<MDL
BEN4	2008/9/11 13:45	38.06915	-122.12308	0.31	<MDL
BEN5	2008/9/11 13:30	38.06785	-122.12279	0.49	<MDL
BRK1	2008/9/26 10:45	37.85054	-122.28874	0.49	0.037
BRK10	2008/9/26 12:35	37.87653	-122.30619	0.10	0.023
BRK11	2008/9/26 11:55	37.87744	-122.30536	0.24	0.074
BRK12	2008/9/26 12:40	37.87675	-122.30511	0.19	<MDL
BRK14	2008/9/26 12:10	37.87790	-122.30324	0.17	0.045
BRK16	2008/9/26 12:25	37.88056	-122.30634	1.11	<MDL
BRK2	2008/9/26 10:55	37.85025	-122.29070	0.48	0.024
BRK3	2008/9/26 11:05	37.85482	-122.29445	0.13	0.122
BRK4	2008/9/26 11:15	37.85649	-122.29483	0.08	0.393
BRK5	2008/9/26 10:30	37.85818	-122.26915	0.17	0.374
BRK7	2008/9/26 11:25	37.86137	-122.29794	0.47	<MDL
BRK8	2008/9/26 11:37	37.86467	-122.29986	0.40	0.458
BRK9	2008/9/26 11:50	37.87321	-122.30415	0.11	<MDL
CON1	2008/9/12 12:30	38.01345	-122.03507	0.24	<MDL
CON2	2008/9/12 12:15	38.00731	-122.03646	0.17	<MDL
ECO01	2007/6/20 0:00	37.90459	-122.31608	0.18	<MDL
EMV1	2008/9/17 14:40	37.83191	-122.28886	0.14	0.210
EMV2	2008/9/17 14:55	37.83539	-122.28750	0.10	0.034
EMV3	2008/9/17 14:05	37.83281	-122.28751	0.20	0.205
EMV4	2008/9/17 15:30	37.84840	-122.29458	0.27	0.007
EMV5	2008/9/17 15:10	37.83984	-122.28926	0.11	<MDL
EMV6	2008/9/17 15:25	37.84829	-122.29464	0.13	<MDL
HWD01	2007/6/21 0:00	37.64489	-122.12605	0.10	<MDL
HWD02	2007/6/21 0:00	37.64510	-122.12069	0.08	<MDL
HWD03	2007/6/21 0:00	37.64970	-122.12260	0.09	<MDL
HWD04	2007/6/27 9:50	37.65281	-122.13822	3.31	<MDL
HWD05	2007/6/27 10:00	37.65014	-122.14343	0.19	<MDL
HWD06	2007/6/27 10:20	37.65196	-122.13996	0.18	<MDL
HWD07	2007/6/27 10:30	37.64783	-122.14001	0.22	<MDL
HWD08	2007/6/27 10:50	37.64664	-122.13564	12.54	<MDL
HWD09	2007/6/27 11:10	37.64938	-122.13644	0.14	<MDL
HWD10	2007/6/27 11:50	37.64482	-122.12730	0.10	<MDL
HWD11	2007/6/27 12:10	37.64088	-122.13308	0.20	<MDL
HWD12	2007/6/27 13:10	37.63778	-122.13564	0.20	0.024

SiteCode	SampleDate	Latitude	Longitude	Mercury (mg/kg)	PCBs (mg/kg)
HWD13	2007/6/27 13:30	37.63791	-122.13313	0.16	<MDL
HWD14	2007/6/27 13:40	37.63781	-122.13483	0.21	<MDL
HWD15	2007/6/27 14:10	37.63815	-122.13117	0.41	<MDL
HWD16	2007/6/27 14:30	37.63942	-122.12936	0.11	<MDL
HWD17	2007/6/27 14:40	37.63819	-122.12725	0.24	<MDL
HWD18	2007/6/27 14:50	37.64035	-122.12669	0.14	0.274
HWD19	2007/6/27 15:10	37.63843	-122.12213	0.26	<MDL
HWD20	2007/6/27 15:30	37.63322	-122.12856	0.23	0.072
HWD21	2007/6/27 15:50	37.63323	-122.12354	1.35	<MDL
HWD22	2007/6/27 16:10	37.63338	-122.11999	0.30	<MDL
HWD23	2007/6/27 16:20	37.64124	-122.11993	0.15	0.063
HWD24	2007/7/3 9:20	37.64970	-122.12365	0.15	0.031
HWD25	2007/7/3 9:40	37.64967	-122.12472	0.28	<MDL
HWD26	2007/7/3 10:30	37.64965	-122.12574	0.09	<MDL
HWD27	2007/7/3 10:50	37.64963	-122.12675	0.29	0.123
HWD28	2007/7/3 11:20	37.64800	-122.12833	0.08	<MDL
HWD29	2007/7/3 13:00	37.64650	-122.12688	0.10	<MDL
HWD30	2007/7/3 13:20	37.64642	-122.12609	0.58	0.400
HWD31	2007/7/3 13:40	37.64636	-122.12536	0.13	<MDL
HWD32	2007/7/3 14:10	37.64633	-122.12234	0.19	0.033
HWD33	2007/7/3 14:30	37.64503	-122.12346	0.07	<MDL
HWD34	2007/7/3 15:00	37.64491	-122.12533	0.12	<MDL
HWD35	2007/7/3 15:10	37.64592	-122.11991	0.11	<MDL
HWD36	2007/7/3 15:50	37.65528	-122.12591	0.15	<MDL
HWD37	2007/7/3 16:20	37.65440	-122.12392	0.10	<MDL
HWD38	2007/7/3 16:40	37.65496	-122.12390	0.08	<MDL
HWD39	2007/7/3 17:00	37.65134	-122.12035	0.17	<MDL
HWD40	2007/7/3 17:20	37.65309	-122.12682	0.31	<MDL
OAK1	2008/9/16 12:25	37.73178	-122.17418	0.27	0.042
OAK10	2008/9/9 12:45	37.75416	-122.19801	0.14	<MDL
OAK11	2008/9/9 12:55	37.75103	-122.19407	0.16	<MDL
OAK12	2008/9/9 13:50	37.76755	-122.20454	0.13	0.033
OAK13	2008/9/9 13:15	37.76136	-122.20498	0.11	<MDL
OAK14	2008/9/9 14:05	37.76395	-122.21481	0.32	0.609
OAK15	2008/9/9 14:20	37.76838	-122.21407	1.22	<MDL
OAK16	2008/9/16 14:15	37.79093	-122.25632	0.15	0.142
OAK18	2008/9/9 14:50	37.77094	-122.21689	0.16	<MDL
OAK19	2008/9/9 15:00	37.76553	-122.22386	0.06	<MDL
OAK2	2008/9/9 10:50	37.73329	-122.17812	0.29	0.155
OAK22	2008/9/9 15:35	37.77395	-122.23412	0.16	0.030
OAK23	2008/9/9 15:45	37.78518	-122.24091	0.38	0.472
OAK24	2008/9/16 15:30	37.79231	-122.25330	0.20	1.270
OAK25	2008/9/16 13:45	37.79245	-122.25840	0.09	<MDL
OAK26	2008/9/16 13:55	37.79121	-122.25955	0.10	0.012
OAK27	2008/9/16 15:15	37.81978	-122.28593	0.66	<MDL
OAK28	2008/9/16 14:40	37.81384	-122.29726	0.13	0.071
OAK29	2008/9/16 14:50	37.82035	-122.28838	0.19	0.437

SiteCode	SampleDate	Latitude	Longitude	Mercury (mg/kg)	PCBs (mg/kg)
OAK30	2008/9/17 13:25	37.81907	-122.28382	0.67	1.281
OAK32	2008/9/17 13:45	37.81669	-122.28113	0.46	0.021
OAK33	2008/9/12 14:05	37.84819	-122.28519	1.72	0.783
OAK4	2008/9/9 11:05	37.73535	-122.17744	0.25	0.103
OAK5	2008/9/9 11:20	37.73622	-122.17867	0.15	0.061
OAK6	2008/9/9 11:35	37.73723	-122.17966	4.85	0.541
OAK7	2008/9/9 12:10	37.74733	-122.18955	0.15	0.083
OAK8	2008/9/16 13:00	37.74973	-122.19277	0.10	0.360
OAK9	2008/9/9 12:14	37.75257	-122.19216	0.59	0.145
PIT1	2008/9/12 9:50	38.01244	-121.84949	0.31	0.015
PIT11	2008/9/12 11:39	38.01197	-121.87199	0.23	0.011
PIT2	2008/9/12 10:05	38.02420	-121.85854	0.39	0.078
PIT3	2008/9/4 15:15	38.03021	-121.86983	0.98	
PIT4	2008/9/12 10:30	38.03045	-121.87094		0.030
PIT5	2008/9/12 10:38	38.03093	-121.87373	0.32	<MDL
PIT6	2008/9/12 11:00	38.02953	-121.89770	0.20	0.014
PIT7	2008/9/12 11:20	38.01360	-121.88848	0.14	<MDL
PIT8	2008/9/12 11:35	38.01148	-121.87968	0.17	<MDL
PORT10	2008/9/4 13:13	37.80893	-122.31233	3.90	0.025
PORT11	2008/9/4 13:55	37.80346	-122.31894	0.10	<MDL
PORT13	2008/9/4 14:35	37.79714	-122.30021	0.09	0.127
PORT14	2008/9/4 13:25	37.80761	-122.31201	0.13	<MDL
PORT15	2008/9/4 12:12	37.81286	-122.31068	0.11	<MDL
PORT16	2008/9/4 12:20	37.81202	-122.31185	0.25	0.096
PORT17	2008/9/4 11:30	37.81553	-122.30817	0.15	<MDL
PORT18	2008/9/4 11:45	37.81394	-122.30736	0.18	0.016
PORT19	2008/9/4 11:00	37.81942	-122.30411	0.13	<MDL
PORT2	2008/9/4 15:10	37.79637	-122.28207	0.62	0.807
PORT4	2008/9/4 15:25	37.79710	-122.28175	3.04	2.120
PORT5	2008/9/4 15:55	37.79724	-122.28143	1.03	7.654
PORT6	2008/9/4 15:35	37.79733	-122.28159	0.69	3.364
PORT7	2008/9/4 14:55	37.79824	-122.28220	0.39	0.332
PORT9	2008/9/4 16:00	37.79691	-122.28040	0.22	0.330
RMD01a	2007/6/19 10:25	37.95413	-122.37723	0.67	<MDL
RMD01b	2007/6/19 10:30	37.95413	-122.37723	0.30	0.062
RMD01c	2007/6/19 10:40	37.95413	-122.37723	0.65	0.521
RMD02a	2007/6/19 10:55	37.95419	-122.37476	0.28	0.226
RMD02b	2007/6/19 11:00	37.95419	-122.37476	0.55	0.112
RMD03	2007/6/19 11:30	37.95070	-122.36341	0.86	<MDL
RMD04	2007/6/19 11:30	37.95110	-122.36375	0.22	0.089
RMD05	2007/6/19 11:45	37.94894	-122.36556	0.06	<MDL
RMD06	2007/6/19 12:00	37.94901	-122.36611	0.14	0.040
RMD07	2007/6/19 0:00	37.94908	-122.36366	0.29	0.023
RMD08a	2007/6/19 12:30	37.94981	-122.36629	0.31	0.009
RMD08b	2007/6/19 0:00	37.94981	-122.36629	0.13	0.908
RMD09	2007/6/19 12:40	37.95039	-122.36687	0.15	<MDL
RMD10	2007/6/19 13:10	37.94764	-122.36308	0.15	0.085

SiteCode	SampleDate	Latitude	Longitude	Mercury (mg/kg)	PCBs (mg/kg)
RMD11	2007/6/19 14:00	37.93390	-122.38078	0.19	0.009
RMD12	2007/6/19 0:00	37.94172	-122.37525	0.40	0.073
RMD13	2007/6/19 14:55	37.93239	-122.36558	0.21	0.159
RMD14	2007/6/19 15:05	37.93175	-122.36384	0.30	0.087
RMD15	2007/6/19 15:30	37.93412	-122.36389	0.13	0.071
RMD16	2007/6/19 15:40	37.93415	-122.36559	0.34	0.044
RMD17	2007/6/19 15:55	37.93414	-122.36075	0.29	0.371
RMD18	2007/6/19 16:20	37.93296	-122.37381	0.48	<MDL
RMD19	2007/6/20 9:50	37.94838	-122.36425	0.39	<MDL
RMD20	2007/6/20 10:20	37.94774	-122.36679	0.26	<MDL
RMD21	2007/6/20 10:45	37.91840	-122.37348	0.30	<MDL
RMD22	2007/6/20 11:00	37.91900	-122.37427	0.36	<MDL
RMD23	2007/6/20 11:15	37.92425	-122.37806	0.54	0.067
RMD24	2007/6/20 11:45	37.92517	-122.37341	0.78	0.821
RMD25	2007/6/20 12:45	37.92534	-122.36906	1.12	1.242
RMD26	2007/6/20 0:00	37.92519	-122.36618	0.64	0.567
RMD27	2007/6/20 13:05	37.92121	-122.36476	0.74	1.187
RMD28	2007/6/20 13:20	37.92400	-122.36206	1.39	1.982
RMD29	2007/6/20 13:35	37.92340	-122.36212	0.71	1.543
RMD30	2007/6/20 13:50	37.92145	-122.36018	0.50	0.673
RMD31	2007/6/20 14:00	37.91958	-122.36020	1.05	0.333
RMD32	2007/6/20 0:00	37.91205	-122.35924	0.21	2.259
RMD33	2007/6/20 14:35	37.91923	-122.35603	0.16	<MDL
RMD34	2007/6/20 15:00	37.92117	-122.35762	0.08	<MDL
RMD35	2007/6/20 15:15	37.92129	-122.35077	0.38	<MDL
SBO01	2007/7/12 10:15	37.63678	-122.41242	0.36	0.033
SBO02	2007/7/12 11:30	37.63717	-122.41161	0.27	0.183
SBO03	2007/7/12 11:50	37.63480	-122.41151	0.15	0.013
SBO04	2007/7/12 10:50	37.63643	-122.41239	0.07	<MDL
SBO05	2007/7/12 11:40	37.63596	-122.41154	0.11	0.160
SBO06	2007/7/12 13:00	37.63893	-122.41247	0.23	<MDL
SBO07	2007/7/12 13:10	37.63919	-122.41240	0.30	0.115
SBO08	2007/7/12 13:30	37.63928	-122.41272	0.20	<MDL
SBO09	2007/7/12 13:50	37.63894	-122.41163	0.21	0.150
SBO10	2007/7/12 14:00	37.63828	-122.41161	0.06	<MDL
SBO11	2007/7/12 14:30	37.63957	-122.41165	0.22	0.119
SBO12	2007/7/12 14:40	37.64113	-122.41148	0.10	<MDL
SBO13	2007/7/12 17:40	37.63830	-122.41341	0.13	<MDL
SCA01	2007/8/23 9:25	37.49801	-122.24270	0.17	0.130
SCA02	2007/8/23 9:38	37.49607	-122.24538	0.13	<MDL
SCA03	2007/8/23 9:55	37.49662	-122.24626	0.30	0.410
SCA04	2007/8/23 10:07	37.49819	-122.24535	0.24	2.224
SCA05	2007/8/23 10:19	37.49871	-122.24611	0.27	0.069
SCA06	2007/8/23 10:28	37.49827	-122.24662	0.13	<MDL
SCA07	2007/8/23 10:40	37.49802	-122.24708	0.19	0.100
SCA08	2007/8/23 10:54	37.49769	-122.24754	0.09	<MDL
SCA09	2007/8/23 11:10	37.49825	-122.24883	0.11	<MDL

SiteCode	SampleDate	Latitude	Longitude	Mercury (mg/kg)	PCBs (mg/kg)
SCA10	2007/8/23 11:37	37.50059	-122.25152	0.12	<MDL
SCA11	2007/8/23 11:54	37.50180	-122.25285	0.28	<MDL
SCA12	2007/8/23 11:07	37.50370	-122.25403	0.13	<MDL
SCA13	2007/8/23 12:17	37.50377	-122.25415	0.21	0.013
SCA14	2007/8/23 12:38	37.50443	-122.25326	0.35	0.301
SCA15	2007/8/23 13:00	37.50605	-122.25063	0.05	<MDL
SCA16	2007/8/23 14:05	37.50371	-122.24857	0.10	0.041
SCA17	2007/8/23 14:22	37.50060	-122.24484	0.18	0.101
SCA18	2007/8/23 14:27	37.50050	-122.24473	0.29	0.058
SCA19	2007/8/23 14:40	37.49921	-122.24663	0.24	0.134
SCA20	2007/8/23 14:48	37.49927	-122.24660	0.15	0.166
SCA21	2007/8/23 14:55	37.50033	-122.24768	0.16	0.098
SCA22	2007/8/23 15:10	37.50006	-122.24404	0.11	0.123
SCA23	2007/8/23 15:21	37.49971	-122.24346	0.16	0.122
SCA24	2007/8/23 15:26	37.49956	-122.24348	0.16	0.282
SCA25	2007/8/23 15:40	37.49885	-122.24229	0.07	0.012
SCA26	2007/8/23 15:58	37.50484	-122.25574	0.09	<MDL
SCA27	2007/8/23 16:10	37.50642	-122.25330	0.06	1.090
SCA28	2007/8/23 16:17	37.50635	-122.25357	0.04	0.185
SCA29	2007/8/24 9:00	37.50751	-122.25196	0.08	0.088
SCA30	2007/8/24 9:10	37.50735	-122.25190	0.15	0.212
SCA31	2007/8/24 9:20	37.50838	-122.25284	0.12	0.870
SCA32	2007/8/24 9:40	37.50719	-122.25446	0.08	<MDL
SCA33	2007/8/24 9:50	37.50696	-122.25574	0.29	0.270
SCA34	2007/8/24 10:00	37.50795	-122.25436	0.13	0.014
SCA35	2007/8/24 10:15	37.50863	-122.25331	0.27	0.052
SCA36	2007/8/24 10:30	37.49967	-122.24462	0.77	0.298
SCA37	2007/8/24 10:40	37.50904	-122.25790	0.06	<MDL
SCA38	2007/8/24 10:40	37.50965	-122.25713	0.07	<MDL
SCA39	2007/8/24 10:50	37.51046	-122.25598	0.13	<MDL
SFO01	2007/9/21 9:00	37.75558	-122.38622	0.10	0.444
SFO02	2007/9/21 9:15	37.75558	-122.38649	0.07	0.282
SFO03	2007/9/21 9:30	37.75556	-122.38673	0.05	0.110
SFO04	2007/9/21 10:00	37.75668	-122.38712	0.13	0.058
SFO05	2007/9/21 10:15	37.75628	-122.38712	0.07	0.101
SFO06	2007/9/21 10:30	37.75572	-122.38704	0.08	0.030
SFO07	2007/9/21 11:15	37.74548	-122.39197	0.51	0.934
SFO08	2007/9/21 11:30	37.74572	-122.39175	0.32	0.249
SFO09	2007/9/21 11:45	37.74598	-122.39153	0.16	0.079
SFO10	2007/9/21 12:00	37.74533	-122.39236	0.44	0.810
SFO11	2007/9/21 12:15	37.74566	-122.39300	0.40	1.160
SFO12	2007/9/21 12:20	37.74386	-122.39320	0.55	1.049
SJO01	2007/6/22 9:30	37.37516	-121.95028	3.26	<MDL
SJO02	2007/6/22 9:50	37.37500	-121.94963	0.09	<MDL
SJO03	2007/6/22 10:30	37.37623	-121.95298	0.08	<MDL
SJO04	2007/6/22 10:45	37.37030	-121.95965	0.12	<MDL
SJO05	2007/6/22 11:45	37.36959	-121.95807	0.24	0.071

SiteCode	SampleDate	Latitude	Longitude	Mercury (mg/kg)	PCBs (mg/kg)
SJO06	2007/6/22 11:40	37.36970	-121.95641	0.16	<MDL
SJO07	2007/6/22 0:00	37.37014	-121.94579	0.10	<MDL
SJO08	2007/6/22 12:25	37.36627	-121.94747	0.23	<MDL
SJO09	2007/6/22 12:40	37.36649	-121.94606	0.07	<MDL
SJO10	2007/6/22 12:50	37.36649	-121.94606	0.14	<MDL
SJO11	2007/6/22 14:05	37.36629	-121.95114	0.13	<MDL
SJO12	2007/6/22 14:40	37.36659	-121.94496	0.15	<MDL
SJO13	2007/6/22 14:55	37.36464	-121.94315	0.07	<MDL
SJO14	2007/6/22 15:15	37.35945	-121.94474	0.76	<MDL
SJO15	2007/6/22 15:45	37.36324	-121.95489	0.27	<MDL
SJO16	2007/6/22 0:00	37.36158	-121.95177	0.10	0.165
SJO17	2007/6/22 16:30	37.34823	-121.92175	0.34	<MDL
SJO18	2007/6/26 9:00	37.34681	-121.92020	0.10	<MDL
SJO19	2007/6/26 9:15	37.34782	-121.91901	0.56	<MDL
SJO20	2007/6/26 9:40	37.34331	-121.91422	0.12	<MDL
SJO21	2007/6/26 9:50	37.34525	-121.91630	0.06	<MDL
SJO22	2007/6/26 10:10	37.34632	-121.91752	0.12	<MDL
SJO23	2007/6/26 10:30	37.34632	-121.91950	0.10	<MDL
SJO24	2007/6/26 10:45	37.34450	-121.91787	0.11	<MDL
SJO25	2007/6/26 11:05	37.34422	-121.91311	0.24	<MDL
SJO26	2007/6/26 11:25	37.34259	-121.91532	0.23	<MDL
SJO27	2007/6/26 11:50	37.33540	-121.90759	0.54	<MDL
SJO28	2007/6/26 12:10	37.33405	-121.90539	0.14	<MDL
SJO29	2007/6/26 14:00	37.34129	-121.90100	0.25	<MDL
SJO30	2007/6/26 14:30	37.31026	-121.86532	0.40	<MDL
SJO31	2007/6/26 15:00	37.30975	-121.86700	0.19	0.313
SJO32	2007/6/26 15:25	37.30839	-121.87276	0.16	<MDL
SJO33	2007/6/26 15:40	37.30867	-121.87540	0.20	<MDL
SJO34	2007/6/26 16:00	37.30618	-121.87856	1.01	<MDL
SJO35	2007/6/26 16:20	37.31236	-121.87038	2.15	<MDL
SJO36	2007/6/26 16:45	37.30582	-121.86951	0.16	0.017
SJO37	2007/6/26 17:15	37.30117	-121.87196	0.13	0.093
SJO38	2007/6/28 10:20	37.31905	-121.86713	0.27	<MDL
SJO39	2007/6/28 10:40	37.31734	-121.87237	0.10	<MDL
SJO40	2007/6/28 11:00	37.32407	-121.87724	0.26	<MDL
SJO41	2007/6/28 11:10	37.32424	-121.87710	0.22	<MDL
SJO42	2007/6/28 11:20	37.32452	-121.87627	0.20	<MDL
SJO43	2007/6/28 11:40	37.32604	-121.87720	0.20	<MDL
SJO44	2007/6/28 11:50	37.32597	-121.87734	0.10	<MDL
SJO45	2007/6/28 0:00	37.32557	-121.87847	0.10	<MDL
SJO46	2007/6/28 13:20	37.30898	-121.85463	6.23	<MDL
SJO47	2007/6/28 13:30	37.31235	-121.85867	0.10	<MDL
SJO48	2007/6/28 13:50	37.31496	-121.86176	0.56	<MDL
SJO49	2007/6/28 14:00	37.31494	-121.86146	0.17	<MDL
SJO50	2007/6/28 14:20	37.31403	-121.86086	0.16	<MDL
SJO51	2007/6/28 14:40	37.31978	-121.86562	0.09	<MDL
SJO52	2007/6/28 15:00	37.31707	-121.86760	0.17	0.010

SiteCode	SampleDate	Latitude	Longitude	Mercury (mg/kg)	PCBs (mg/kg)
SJO53	2007/6/28 15:30	37.31554	-121.86649	0.72	<MDL
SJO54	2007/6/28 16:00	37.31239	-121.86361	0.22	0.055
SJO55	2007/6/28 16:20	37.30926	-121.86012	0.12	<MDL
SJO56	2007/6/28 17:00	37.32075	-121.87609	0.22	<MDL
SJO57	2007/6/28 17:20	37.32280	-121.87480	0.25	<MDL
SLO01	2007/7/18 8:50	37.71513	-122.19130	0.34	0.171
SLO02	2007/7/18 9:00	37.71563	-122.18961	1.19	1.266
SLO03	2007/7/18 9:20	37.71616	-122.18776	0.61	0.283
SLO04	2007/7/18 9:40	37.72152	-122.19002	0.03	<MDL
SLO05	2007/7/18 10:00	37.72164	-122.19056	0.12	0.106
SLO06	2007/7/18 10:20	37.72287	-122.19298	0.96	<MDL
SLO07	2007/7/18 10:40	37.71780	-122.18938	0.13	<MDL
SLO08	2007/7/18 10:50	37.71650	-122.18479	0.11	0.043
SLO09	2007/7/18 0:00	37.71513	-122.18616	0.24	0.055
SLO10	2007/7/18 11:40	37.71204	-122.18474	0.09	<MDL
SLO11	2007/7/18 12:50	37.70910	-122.18008	0.11	<MDL
SLO12	2007/7/18 13:20	37.71511	-122.17359	0.21	0.070
SLO13	2007/7/18 13:40	37.71487	-122.17394	0.13	<MDL
SLO14	2007/7/18 13:50	37.71045	-122.17220	0.15	<MDL
SLO15	2007/7/18 14:10	37.70581	-122.17767	0.17	<MDL
SLO16	2007/7/18 14:20	37.70790	-122.17310	0.13	0.023
SLO17	2007/7/18 14:40	37.70481	-122.17078	0.15	<MDL
SLO18	2007/7/18 15:00	37.70448	-122.17191	0.15	<MDL
SLO19	2007/7/18 15:10	37.70605	-122.16907	0.15	<MDL
SLO20	2007/7/18 15:20	37.70295	-122.16956	0.04	<MDL
SLO21	2007/7/18 15:30	37.70280	-122.16961	0.31	<MDL
SLO22	2007/7/18 15:50	37.70113	-122.17374	0.10	<MDL
SLO23	2007/7/18 16:10	37.69591	-122.16956	0.13	<MDL
SLO24	2007/7/18 16:30	37.69299	-122.16432	0.11	<MDL
SLO25	2007/7/18 16:40	37.69965	-122.17506	0.09	0.184
SLO26	2007/7/19 12:00	37.71704	-122.16116	0.31	<MDL
SLO27	2007/7/19 12:20	37.71673	-122.15953	0.19	<MDL
SLO28	2007/7/19 12:30	37.71269	-122.15704	0.14	<MDL
SLO29	2007/7/19 12:50	37.70816	-122.14594	0.09	<MDL
SLO30	2007/7/19 13:20	37.70538	-122.14328	0.16	<MDL
SLO31	2007/7/19 13:30	37.70542	-122.14365	0.15	<MDL
SLO32	2007/7/19 13:50	37.70792	-122.14200	0.06	0.148
SLO33	2007/7/19 14:00	37.71395	-122.15040	0.13	<MDL
SLO34	2007/7/19 14:10	37.71019	-122.15173	0.31	<MDL
SLO35	2007/7/19 14:20	37.71034	-122.15184	0.31	<MDL
SLO36	2007/7/19 14:50	37.71158	-122.15289	0.06	<MDL
SLO37	2007/7/19 15:00	37.71170	-122.15440	0.18	<MDL
SLO38	2007/7/19 15:40	37.70993	-122.15836	0.11	<MDL
SLO39	2007/7/19 16:20	37.71656	-122.15699	0.36	<MDL
SLO40	2007/7/19 16:50	37.70280	-122.16220	0.12	0.063
SSO01	2007/7/5 16:00	37.63969	-122.40379	0.18	0.331
SSO02	2007/7/5 16:10	37.64119	-122.40360	0.06	<MDL

SiteCode	SampleDate	Latitude	Longitude	Mercury (mg/kg)	PCBs (mg/kg)
SSO03	2007/7/5 16:40	37.65189	-122.39436	1.24	<MDL
SSO05	2007/7/12 11:00	37.63693	-122.41236	0.47	<MDL
SSO10	2007/7/12 13:30	37.64809	-122.41248	0.34	0.432
SSO15	2007/7/12 15:10	37.64086	-122.41239	0.17	<MDL
SSO16	2007/7/12 15:20	37.64249	-122.41122	0.03	<MDL
SSO17	2007/7/12 15:30	37.64581	-122.41003	0.08	<MDL
SSO18	2007/7/12 16:00	37.64205	-122.41241	0.01	<MDL
SSO19	2007/7/12 16:20	37.64712	-122.41299	0.12	0.045
SSO20	2007/7/12 16:30	37.64755	-122.41640	0.05	<MDL
SSO21	2007/7/12 16:40	37.64762	-122.41660	0.08	<MDL
SSO22	2007/7/12 17:10	37.64729	-122.41800	0.09	0.132
SSO24	2007/7/12 18:00	37.64892	-122.41466	0.10	0.021
SSO25	2007/7/12 18:20	37.64298	-122.41739	0.12	0.032
SVA01	2007/7/5 0:00	37.39782	-122.02437	0.16	<MDL
SVA02	2007/7/5 10:00	37.39704	-122.01173	0.09	<MDL
SVA03	2007/7/5 10:15	37.39830	-122.02322	0.13	<MDL
SVA04	2007/7/5 10:40	37.40839	-122.02715	0.30	<MDL
SVA05	2007/7/5 11:30	37.37580	-122.01664	0.14	<MDL
SVA06	2007/7/5 11:45	37.37693	-122.02454	0.11	0.245
SVA07	2007/7/5 12:00	37.37801	-122.02804	0.07	0.345
SVA08	2007/7/5 12:15	37.38101	-122.02473	0.10	1.375
SVA09	2007/7/5 12:40	37.37986	-122.02037	0.09	0.822
UCC1	2008/9/11 12:25	38.05584	-122.22009	0.22	<MDL
UCC3	2008/9/11 13:20	38.04856	-122.24789	0.86	<MDL
UCC4	2008/9/11 15:40	38.02796	-122.26614	0.11	<MDL
UCC5	2008/9/11 15:45	38.02785	-122.26610	0.27	<MDL
UCC6	2008/9/11 14:35	38.00945	-122.09631	0.11	<MDL
UCC7	2008/9/11 14:45	38.01287	-122.08746	0.18	<MDL
VLJ1	2008/9/11 9:50	38.09832	-122.25330	1.42	<MDL
VLJ2	2008/9/11 9:35	38.09907	-122.24509	1.14	0.020
VLJ3	2008/9/11 11:30	38.09964	-122.27180	0.44	0.325
VLJ4	2008/9/11 10:30	38.09116	-122.26482	0.23	0.663
VLJ5	2008/9/11 10:45	38.09219	-122.26569	0.23	0.056
VLJ6	2008/9/11 10:57	38.09254	-122.26637	0.40	0.923
VLJ7	2008/9/11 10:10	38.09056	-122.26231	0.33	0.067
VLJ8	2008/9/11 11:12	38.09575	-122.26632	0.08	0.007
VLJ9	2008/9/11 11:40	38.09927	-122.27029	0.94	0.740
75%ile				0.31	0.102
Median				0.17	<MDL
25%ile				0.11	<MDL
Mean			(<MDL =0)	0.37	0.171