

Applying Sediment Quality Objective Assessment Protocols to Two San Francisco Bay 303(d)-Listed Sites

FINAL REPORT

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Final Report

RMP Contribution 699

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Executive Summary

In 2009, the State Water Resources Control Board (State Water Board) adopted a set of narrative sediment quality objectives (SQOs) and a standardized assessment framework to determine the impact of chemical contamination on benthic communities. The SQO framework uses multiple lines of evidence (MLOE), known as the sediment triad approach, to assess sediment quality as measured by chemistry, toxicity, and benthic community condition. This study used the standardized SQO methodology to examine whether Mission Creek and San Leandro Creek would still be labeled as impaired 15 years after the Bay Protection and Toxic Cleanup Program (BPTCP) listed the sites as toxic hotspots. Spatial trends in sediment contamination were also analyzed by comparing the narrow creek channels to nearby open Bay sites from the Regional Monitoring Program's (RMP) 2011 and 2012 Status and Trends sediment cruise. It is important to note that the 1998 BPTCP report classified all of San Leandro Bay as impaired, whereas this study only sampled San Leandro Creek, one of the most contaminated portions of the shallow embayment.

The two creeks were sampled on gradient; three samples were taken at each site at the upper, mid, and lower end of the channels. The open Bay sampling locations were selected based on the RMP's probabilistic (random, spatially balanced) sampling design. At each sampling site the following contaminants were sampled: trace metals (Cd, Cu, Pb, Hg, and Zn), polycyclic aromatic hydrocarbons (PAHs), pesticides (Chlordanes, Dieldrin, Trans Nonachlor, DDDs, DDEs, DDTs), and polychlorinated biphenyls (PCBs). The Chemistry LOE score was calculated by averaging the California Logistic Regression Model (CA LRM) and the Chemical Score Index (CSI) results. The toxicity LOE score was obtained by averaging the results from an acute and a sublethal toxicity test. The benthic infauna community condition score was the median of four benthic indices scores. The three LOE scores were then integrated to obtain an overall station assessment score (Clearly Impacted, Likely Impacted, Possibly Impacted, Likely Unimpacted, and Unimpacted).

In both creeks, the upper end of the channel was considered Clearly Impacted. However, the sediment quality improved in both locations relative to the proximity of the open Bay. The site closest to the open Bay (end-gradient) in Mission Creek and the mid- and end-gradient in San Leandro Creek were all classified as Likely Impacted. Nevertheless, both creek channels classification as either Clearly and Likely Impacted indicates that both Mission Creek and San Leandro Creek remain impaired 15 years after the BPTCPs original designation.

In the open Bay only one of the sampling sites was listed as Likely Impacted and none of the sites were listed as Clearly Impacted; the majority of the nearby open Bay stations were classified as Possibly Impacted. The lower sediment quality in the two creeks, compared to the open Bay, and the presence of contamination gradient within the creek channels suggest that the contamination in the channels is most likely from nearby industrial sites and stormwater runoff.

Introduction

As part of the 2009 “Water Quality Control Plan for Enclosed Bays and Estuaries,” the State Water Resources Control Board (State Water Board) adopted a set of narrative sediment quality objectives (SQOs) and a standardized assessment framework to determine the impact of chemical contamination on benthic communities (Beegan and Bay 2012). The SQO framework uses multiple lines of evidence (MLOE), known as the sediment triad approach, to assess sediment quality as measured by chemistry, toxicity, and benthic community condition. Incorporating MLOE increases confidence in accurately predicting sediment quality; a single indicator cannot reliably evaluate whether contaminants in sediment pose a risk to ecosystem health (Bay and Weisberg 2012). The sediment quality triad has been in use since Long and Chapman (1985) first described the MLOE approach. However, a standardized method for assessing sediment quality using MLOE was not established until the State Water Board adopted the SQO assessment framework. This study employed the SQO assessment method to determine if 303(d)-listed sites, which were identified as candidate toxic hotspots by the Bay Protection and Toxic Cleanup Program (BPTCP) in 1998, are still considered impaired 15 years after the BPTCP’s original designation.

In 1997, the BPTCP conducted sediment sampling at potential hotspots in San Francisco Bay. Eight of the sites sampled were listed as candidate toxic hotspots. As a result, four of the eight sites were included on the 2002 303-(d) list including: Mission Creek, San Leandro Bay, Castro Cove, and Islais Creek. In this study, two of the 303-(d) listed sites were examined: 1) Mission Creek, on the west side of Central Bay, and 2) San Leandro Bay, east of the Oakland International Airport. BPTCP determined that the most contaminated stations in San Leandro Bay were in San Leandro Creek. Therefore, this study only sampled within San Leandro Creek. Both sites are narrow creek channels; three samples (located at or near the 1997 BPTCP stations) were taken along a gradient in both creeks to characterize the spatial extent of contamination (Figure 1).

The study’s objectives were to evaluate whether the creeks would still be labeled as impaired using the standardized SQO methodology and to evaluate whether spatial and temporal trends in sediment contamination exist. To examine spatial trends, nearby sites from the Regional Monitoring Program (RMP) 2011 and 2012 Status and Trends (S&T) sediment cruise were analyzed using the SQO methodology. Central Bay RMP S&T sites were included to facilitate a comparison between the open Bay sites versus the narrow creek channels.

The 1998 BPTCP report also employed a sediment quality triad to determine the degree of sediment contamination at the two creek sites. However, the methodology used to assess the individual lines of evidence differed; for example, the BPTCP used only the relative benthic index (RBI) to assess benthic community condition (Hunt et al. 1998), while the SQO methodology integrates the results from four benthic indices.

BPTCP previously labeled all three Mission Creek stations as significantly polluted, with elevated chemistry, high toxicity, and a degraded benthic community. In 2002, the San Francisco Public Utilities Commission contracted with Battelle to evaluate the BPTCP designation of Mission Creek as a toxic hotspot (Battelle 2002). Despite elevated chemistry, the report

concluded that none of the stations in Mission Creek were toxic hotspots because of non-recurrent toxicity. The difference in the results may be in part attributed to different analytical methods. The toxicity methodology differed between the two studies; Battelle had a longer acclimation period for test organisms and replaced water if hydrogen sulfide and ammonia levels exceeded threshold limits. Additionally, Battelle did not assess benthic community condition, which was critical in BPTCP's designation of Mission Creek as a hotspot.

Two of the three San Leandro Bay stations analyzed in this study were examined in the 1998 BPTCP report. The upper creek channel site exhibited elevated chemistry and high toxicity (Hunt et al. 1998). Although BPTCP did not sample at this study's mid-gradient site, a nearby BPTCP station possessed elevated chemistry and mixed biological effects. In 1998, the San Francisco Estuary Institute (SFEI) evaluated sediment chemistry in San Leandro Creek, but toxicity and benthic community condition were not assessed (Daum et al. 2000).

Results from the reports described above were used to examine trends for pollutant concentrations, benthic indices, and toxicity in the two creek channels. It is important to note that some of the Battelle (2002) and Daum et al. (2000) sampling stations that will be compared to this study's sample stations are not identical; however, the sampling locations were close enough to be used in time-series comparisons.

Methods

Field Methods

The two creek channels were sampled on gradient; three samples were taken at each site at the upper, mid, and lower end of the creek channels (Figure 1).

Mission Creek channel is a remnant of Mission Bay rather than its namesake creek whose mouth was further west. Surrounded on three sides by fill, it is an urban, mostly concrete- and rip-rap lined channel with pockets of vegetation that enters the Bay on the eastern side of the present-day San Francisco waterfront (Battelle 2002). The channel has been a dead-end slough for more than 100 years and was historically industrial; lumber mills, municipal dumps, incinerators, ship-building yards, and other similar industries were formerly located along the channel. Currently, seven combined sewer discharge (CSD) points potentially discharge into Mission Creek during wet weather events.

San Leandro Creek is an urban creek near the Oakland airport (Hunt et al. 1998). Current industries adjacent to the creek include roofing, lighting, auto maintenance and tire sales, and crane and rigging companies. Historically, metal plating and lead manufacturing industries were located near the creek (Daum et al. 2000).

San Leandro and lower Mission Creek samples were collected by boat on August 25, 2011. The upper and mid Mission Creek samples were collected on September 1, 2011. At both sites, sampling began at the outermost site and moved inward to minimize sediment disturbance and cross contamination. The five RMP S&T 2011 samples were collected from August 24-26, 2011.

The three RMP S&T 2012 samples were collected by boat on April 19, 2012. Thus, the sampling took place during the dry season in 2011 and during the wet season in 2012.

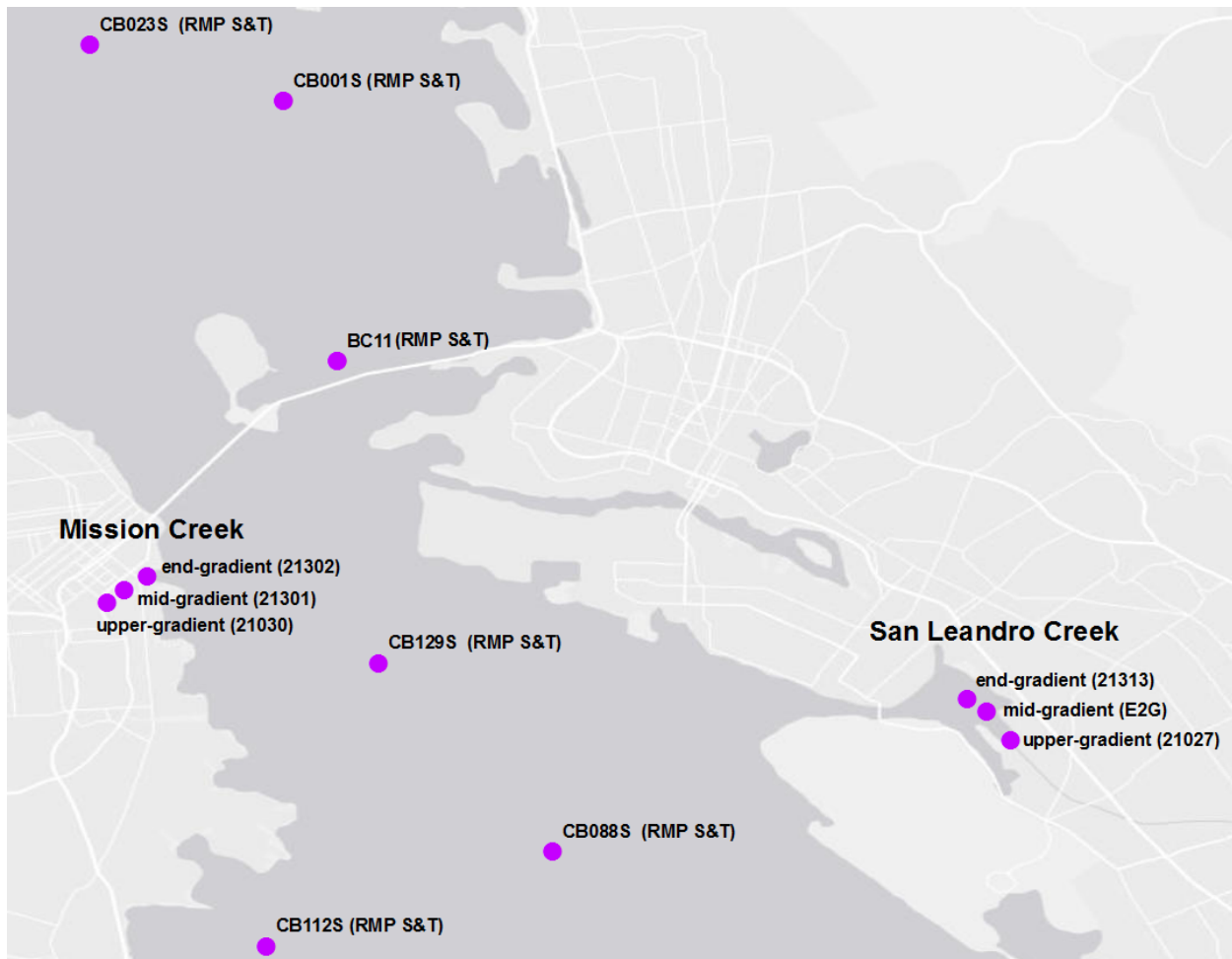


Figure 1: Sampling locations for Mission Creek and San Leandro Creek and the 2011 and 2012 RMP S&T sites.

Chemistry and toxicity samples were collected using a Young-modified Van Veen grab with a surface area of 0.1 m². A composite sample for sediment chemistry was obtained by collecting the top 5 cm of sediment from two or three grab samples taken at each site. The Halar® coated sampling equipment was cleaned with detergent, acid, and methanol, and then rinsed with ultrapure water at each sampling location. Benthic infauna samples were collected with a 0.05 m² surface area Ponar grab and screened through 0.5- and 1.0-mm nested sieves before being placed into sample jars, relaxed in MgSO₄, and fixed with 10% buffered formalin.

Laboratory Methods

These samples were analyzed by the same methods and laboratories as the RMP S&T samples. Trace organic analyses were completed by the East Bay Municipal Utility District (EBMUD) laboratory using EPA Method 8270 (PAHs), EPA Method 1668A (PCBs), and a modified version of EPA Method 1668A (pesticides). Trace metal analyses were conducted by the City

and County of San Francisco (CCSF) using a modified version EPA digest Method 3050B and a modified EPA analysis Method 6020A.

Toxicity tests were conducted by the UC Davis-Granite Canyon Laboratory. Both an acute and a sublethal toxicity test were performed: 1) a 10-day whole-sediment toxicity test using the amphipod *Eohaustorius estuarius* with percent survival as the endpoint and 2) a 48-hour sediment-water interface toxicity (SWI) test using the bivalve *Mytilus galloprovincialis* with the percentage of embryos that developed normally and were alive as the endpoint. Five replicates were prepared for each test and the mean of the replicates' percent survival or development was reported. For the acute amphipod toxicity test, EPA Method 600/R-94-025 was used. For the sublethal bivalve test, EPA Method 600/R-95-136M was used. Benthic infauna taxonomy was completed by CCSF-Oceanside Biology Laboratory and Moss Landing Marine Laboratories-Oakden Lab.

SQO Assessment Methods

Data compilation was performed by SFEI and sent to Dr. Steve Bay at the Southern California Coastal Water Research Project (SCCWRP) for SQO analyses. Three LOEs were used to assess sediment quality: chemistry, toxicity, and benthic community condition. Four response categories classified the level of chemical exposure, benthic disturbance, or toxicity (Table 1).

Table 1: Categorical scores for the three lines of evidence.

Category Score	Chemistry LOE	Benthic LOE	Toxicity LOE
1	Minimal Exposure	Reference	Nontoxic
2	Low Exposure	Low Disturbance	Low Toxicity
3	Moderate Exposure	Moderate Disturbance	Moderate Toxicity
4	High Exposure	High Disturbance	High Toxicity

The contaminants included in the chemistry LOE calculation are listed in Table 2. The chemistry LOE was calculated by integrating two sediment quality guideline values: 1) the California Logistic Regression Model (CA LRM) and 2) the Chemical Score Index (CSI) (Bay and Weisberg 2012). The CA LRM uses logistic regressions to predict the probability of sediment toxicity based on pollutant concentrations (Bay et al. 2012). The regression model with the highest p value (probability of observing a toxic effect) becomes the CA LRM value. The CSI evaluates the magnitude of benthic community disturbance based on contaminant concentrations (Ritter et al. 2012). The concentration of each contaminant is compared to threshold values and assigned a benthic disturbance category. The CSI score is calculated by multiplying the benthic disturbance category by a weighting factor (based on the strength of the association between the chemical score and the benthic response). The CA LRM and CSI are averaged to obtain a chemistry LOE score; the scores are then assigned to one of four response categories (Table 1).

Table 2: Sediment contaminants evaluated in the SQO assessments.

Cadmium (mg/kg)	LPAH (ug/kg) ^b	DDEs, total (ug/kg)
Copper (mg/kg)	Alpha Chlordane (ug/kg)	DDTs, total (ug/kg) ^c
Lead (mg/kg)	Gamma Chlordane (ug/kg)	4,4'-DDT (ug/kg)
Mercury (mg/kg)	Dieldrin (ug/kg)	PCBs, total (ug/kg) ^d
Zinc (mg/kg)	Trans Nonachlor (ug/kg)	
HPAH (ug/kg) ^a	DDD, total (ug/kg)	

^a Total HPAHs are equivalent to the sum of Pyrene, Fluoranthene, Benzo(a)anthracene, Chrysene, Benzo(a)pyrene, Benzo(e)pyrene, and Perylene

^b Total LPAHs are equivalent to the sum of Naphthalene, 1-methylnaphthalene, 2-methylnaphthalene, Acenaphthene, Biphenyl, Fluorene, Phenanthrene, 1-methylphenanthrene, Anthracene

^c Total DDTs are equivalent to the sum of 2,4'-DDT and 4,4'-DDT

^d Total PCBs are equivalent to the sum of PCB 8, PCB 18, PCB 28, PCB 44, PCB 52, PCB 66, PCB 101, PCB 105, PCB 110, PCB 118, PCB 128, PCB 138, PCB 153, PCB 180, PCB 187, PCB 195

The toxicity LOE scores were obtained by assigning both the acute and sublethal toxicity tests a score of 1-4 (Greenstein and Bay 2012). The scores were based on threshold levels of percent survival or percent of larvae exhibiting normal growth and in addition to whether the results were statistically different from the controls (Table 3). The average of the two scores became the overall toxicity LOE score (nontoxic, low, moderate, or high toxicity).

Table 3: Category scores (1-4) for the acute and sublethal toxicity tests

Category Score		1	2	3	4
	Statistical Significance	Nontoxic (%)	Low Toxicity (% of control)	Moderate Toxicity (% of control)	High Toxicity (% of control)
<i>Eohaustorius</i> Survival	Significant	90-100	82-89	59-81	<59
<i>Mytilus</i> Normal	Significant	80-100	77-79	42-76	<42

The benthic LOE score is the median of four benthic indices scores: 1) the Index of Biotic Integrity (IBI), 2) the Relative Benthic Index (RBI), 3) the Benthic Response Index (BRI), and 4) the River Invertebrate Prediction and Classification System (RIVPACS) (Bay and Weisberg 2012).

The SQO framework evaluates two questions: 1) is there biological degradation? and 2) is the chemical exposure high enough to generate a biological response? (Bay and Weisberg 2012). To answer whether there is biological degradation, the toxicity and benthic LOE scores are evaluated; the benthic score is given more weight because the benthic community condition is a more direct indicator of sediment quality than toxicity tests. To determine whether there is chemical exposure that will cause a biological response, the toxicity and chemistry LOE scores are considered. The final data integration step combines the severity of the biological effect and the potential for chemically mediated effects to assign the site one of six station assessments:

Table 4: SQO station assessments and scores

Station Assessment	SQO Score
Unimpacted	1
Likely Unimpacted	2
Possibly Impacted	3
Likely Impacted	4
Clearly Impacted	5
Inconclusive	6

Both the Likely and Clearly Impacted station assessments (SQO score of 4 or 5) indicate that the site's sediment quality is degraded. Both biological effects and chemical effects must be in evidence for a site to be listed as impacted (Barnett et al. 2008).

Results

The SQO methodology was used to evaluate whether the two 303(d)-listed creeks remain impaired 15 years after their original designation. The SQO station assessments at both Mission Creek and San Leandro Creek are either "Clearly Impacted" or "Likely Impacted," indicating sediment quality at both sites remains degraded (Tables 5 and 6). At both sites, the upper-gradient had an SQO score of 5, but closer to the open Bay the SQO score changed to 4. At Mission Creek, the end-gradient was listed as Likely Impacted; while at San Leandro Creek, the station assessment switched to Likely Impacted by the mid-gradient sample site.

The improvement in Mission Creek's SQO score at the end-gradient was driven by the change from high chemical exposure and high toxicity to moderate exposure and moderate toxicity (Table 5). The benthic community LOE remained constant, with all three stations exhibiting moderate disturbance.

At San Leandro Creek the lower SQO score (indicating improved conditions) at the mid- and end-gradient was driven by the change from high chemical exposure at the upper end of the channel to moderate exposure at the mid- and end-gradients (Table 6). All three stations sampled in San Leandro Creek had moderate toxicity and moderate benthic community disturbance.

Table 5: SQO results for the MLOEs and overall Mission Creek station assessment.

<i>Station Name</i>	<i>Chemical Exposure</i>	<i>Toxicity</i>	<i>Benthic Disturbance</i>	<i>Station Assessment</i>
Mission Creek (upper-gradient)	High	High	Moderate	Clearly Impacted
Mission Creek (mid-gradient)	High	High	Moderate	Clearly Impacted
Mission Creek (end-gradient)	Moderate	Moderate	Moderate	Likely Impacted

Table 6: SQO results for the MLOEs and overall San Leandro Creek station assessment.

<i>Station Name</i>	<i>Chemical Exposure</i>	<i>Toxicity</i>	<i>Benthic Disturbance</i>	<i>Station Assessment</i>
San Leandro (upper-gradient)	High	Moderate	Moderate	Clearly Impacted
San Leandro (mid-gradient)	Moderate	Moderate	Moderate	Likely Impacted
San Leandro (end-gradient)	Moderate	Moderate	Moderate	Likely Impacted

The SQO results provide a narrative representation of sediment quality in the creek channels. To provide a quantitative understanding of the chemistry, toxicity, and benthic community condition at each station, the mean effects range-median quotients (mERMqs), the toxicity of the acute and sublethal tests, and the three most common benthic species identified in the sample are shown in Table 7.

In previous RMP reports, mERMqs were used to determine the extent of chemical contamination. Additionally, mERMq values are significantly correlated with CA LRM and CSI scores (Thompson and Lowe 2008). When mERMq values are above 0.5, the probability of a toxic effect is 82% (Thompson et al. 1999). For both the upper and mid-gradient stations in Mission Creek and San Leandro Creek, the mERMqs were above 0.5 (Table 7). The mERMq values decreased from the upper channel toward the open Bay for both Mission Creek and San Leandro Creek (Table 7). Mission Creek's upper gradient was the most degraded sample from either creek. The mERMq for the station was 1.98, the percent survival and percent development was the lowest of all six samples, and the two negative indicator species (*Capitella capitata* and *Oligochaeta*) for the RBI were present in the sample.

Table 7: mERMq values, percent survival and percent normal development results, and the three most abundant benthic species in the Mission Creek and San Leandro Creek samples.

Station Name	mERMq	<i>Eohaustorius</i> Mean % survival (control adjusted)	<i>Mytilus</i> Mean % normal (control adjusted)	Most Common Benthic Species
Mission Creek (upper-gradient)	1.98	53	3	1) <i>Capitella capitata</i> complex 2) Eteone Species 3) Oligochaeta
Mission Creek (mid-gradient)	0.55	60	34	1) <i>Cossura</i> species A 2) Oligochaeta 3) <i>Nippoleucon hinumensis</i>
Mission Creek (end-gradient)	0.15	73	66	1) <i>Cossura</i> species 2) Oligochaeta 3) <i>Nippoleucon hinumensis</i>
San Leandro (upper-gradient)	0.95	61	82	1) <i>Gemma gemma</i> 2) <i>Streblospio benedicti</i> 3) <i>Musculista senhousia</i>
San Leandro (mid-gradient)	0.52	63	59	1) <i>Scoletoma tetraura</i> complex 2) <i>Streblospio benedicti</i> 3) <i>Ampelisca abdita</i> and Oligochaeta
San Leandro (end-gradient)	0.32	68	69	1) <i>Pseudopolydora paucibranchiata</i> 2) Oligochaeta 3) <i>Musculista senhousia</i>

Results from the 1998 BPTCP report, 2002 Battelle report, and the Daum et al. (2000) study were examined to determine if contamination at the Mission Creek and San Leandro Creek sites had changed over time. At both sites, amphipod toxicity showed no apparent trend over time. For both the upper and mid-gradient of Mission Creek, toxicity initially decreased after 1997, but significant toxicity recurred around the year 2000. Toxicity increased at the end-gradient of Mission Creek; however, there were only three toxicity samples taken at the site in 14 years. For

San Leandro Creek samples, toxicity decreased at the upper-gradient (n=3), increased at the mid-gradient (n=2), and remained the same at the end-gradient (n=2). Similarly, there was no clear temporal trend for RBI scores. It is important to note that the RBI was calculated only in 1997 and 2011. The RBI remained the same for both Mission Creek's upper and end-gradient. At the mid-gradient of Mission Creek and the end-gradient of San Leandro Creek the RBI decreased.

Lead and chlordane were the only two contaminants that exhibited a temporal trend. At the upper and mid-gradient Mission Creek stations and at the end-gradient of San Leandro creek, lead levels have decreased over time (Figure 2). At all the stations where there were adequate data to analyze temporal trends, chlordane levels decreased (Figure 3). Alpha chlordane levels at the upper and mid-gradient of Mission Creek have decreased; gamma chlordane levels at the end-gradient of Mission Creek and the mid-gradient of San Leandro Creek have also decreased.

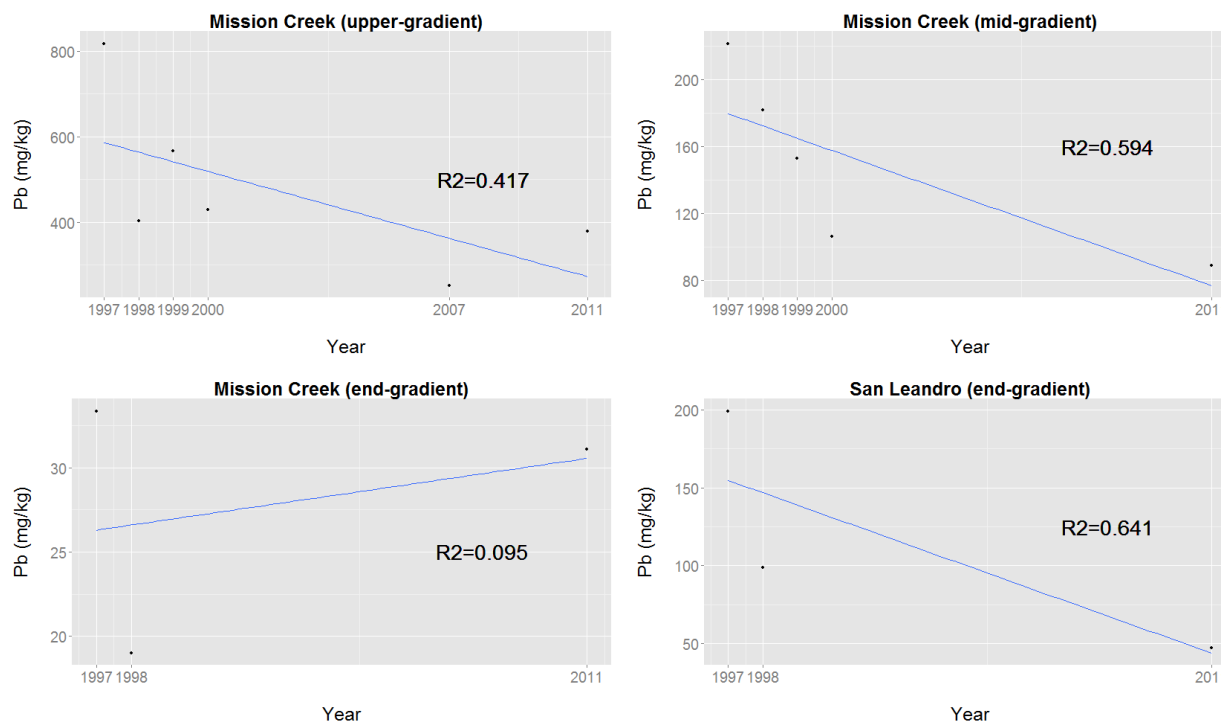


Figure 2: Linear regressions of lead concentrations over time at all of the hotspot stations where there were adequate data to assess temporal trends. R-squared values are displayed in the plots.

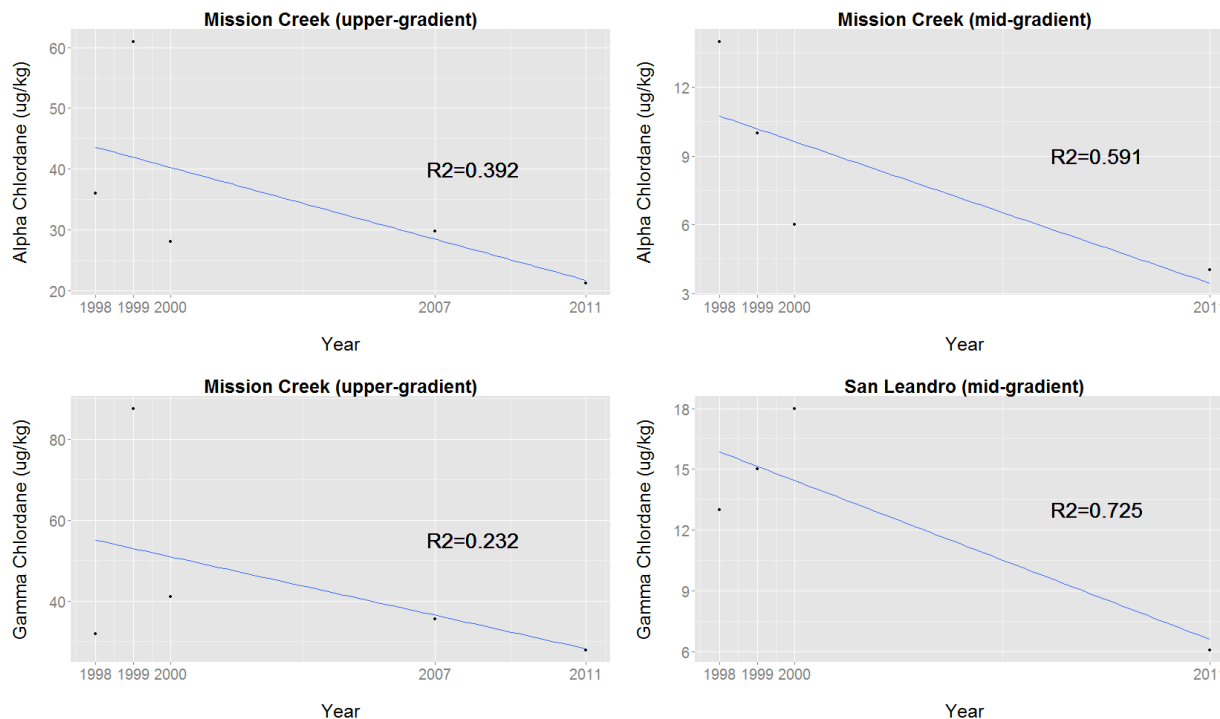


Figure 3: Linear regressions of chlordanes concentrations over time at the hotspot stations where there were adequate data to assess temporal trends. R squared values are displayed in the plots

The SQO station assessments for the RMP S&T Central Bay sites were compared to the SQO scores from the two creeks. The contamination in the narrow creek channels was greater than in the open Bay. The only sampling stations categorized as clearly impacted in Central Bay were in Mission Creek and San Leandro Creek (Figure 4).

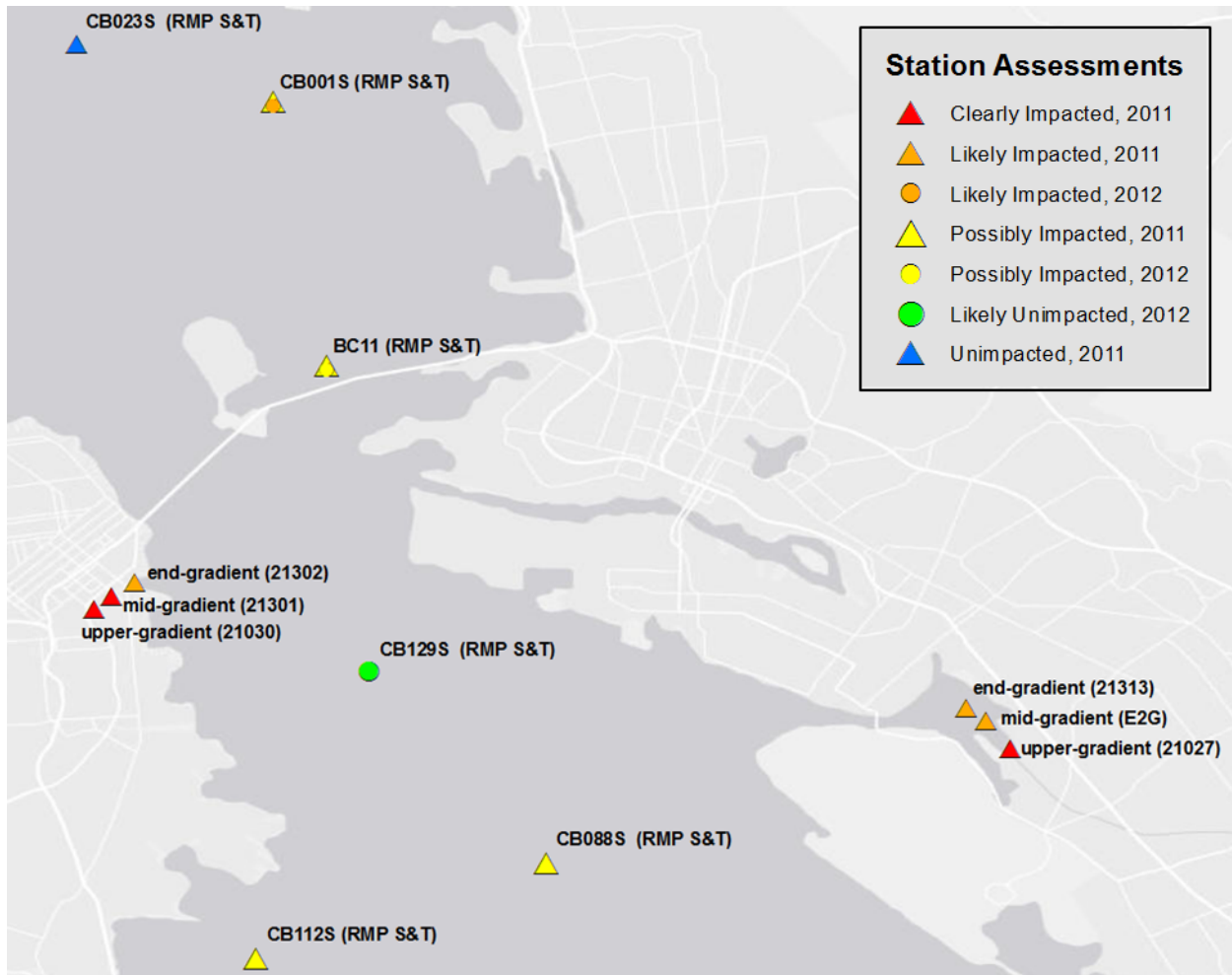


Figure 4: SGO station assessments for the six hotspot sampling locations and the RMP S&T Central Bay sites.

Conclusions

The SGO station assessments of Clearly and Likely Impacted for Mission Creek and San Leandro Creek indicate that the two sites remain impaired 15 years after BPTCP classified the sites as hotspots. All three stations in both creek channels were given an SGO score of either 4 or 5, indicating both creek channels are degraded.

Comparing individual BPTCP station assessments to the SGO results is difficult because BPTCP classified the three LOEs only as degraded or not degraded. However, Mission Creek's listings as Clearly and Likely Impacted support BPTCP's 1998 finding that all three Mission Creek stations possess elevated chemistry, recurrent toxicity, and a degraded benthos. BPTCP listed San Leandro Bay as a hotspot because the upper and mid-portions of the San Leandro Creek channel had elevated chemistry and mixed biological impacts. Similarly, the SGO results at the upper and mid-gradients exhibited moderate biological impacts and moderate to high chemical exposure. The one clear difference between the two assessments is the BPTCP did not list the end-gradient of San Leandro Creek as degraded. The variance may be because different indices were used to calculate the three LOEs; the condition of the site may have worsened; or the Bay's

high seasonal variability may have altered the spatial extent of pollution. Overall, this study's results suggest that both creek channels are clearly degraded, supporting BPTCP's 1998 findings.

Over the past 15 years, there have been no significant decreases in pollutant levels, except for reductions in lead and chlordane concentrations. The significance of decreasing chlordane concentrations is unknown. Phillips et al. (2008) found that amphipod toxicity is most likely caused by a mixture of organic chemicals, including pesticides. But, toxicity was not induced when *Eohaustorius estuarius* were exposed to *trans*-chlordane concentrations that were over a thousand times higher than environmentally relevant concentrations (Phillips et al. 2011).

At all six of the stations, the benthos are moderately disturbed, suggesting that sediment quality is directly affecting the benthic community condition. It is important to note that non-contaminant factors, such as grain size, poor tidal circulation, and salinity, could be affecting toxicity and the benthic community. In addition, typically negative indicator species such as *Capitella capitata* and *Oligochaeta* can occur naturally, in the absence of contamination or disturbance, in organically enriched environments such as dead-end sloughs. However, the six stations possess either moderate or high chemical exposure; therefore pollutant concentrations are likely a causal factor. A Mission Creek toxicity identification evaluation (TIE) study found that the cause of toxicity was most likely a mix of organic chemicals; however, specific contaminants were not positively identified. This TIE study was limited by available chemical procedures, gaps in literature toxicity values, and the likely presence of unmeasured contaminants (Phillips et al. 2008). Before subsequent TIEs are performed at the creeks, TIE methods should be developed further.

The higher SQO scores in the two creeks, compared to the open Bay, and the presence of contamination gradient within the creek channels suggest that the contamination in Mission and San Leandro creeks is most likely from nearby industrial sites and stormwater runoff. Toxic sediments in San Francisco Bay are associated with urban creek inputs (Anderson et al. 2007). Barnett et al. (2008) also concluded that SQO scores were higher near the perimeters of California embayments, closer to ports and commercial areas.

This study successfully applied the standardized SQO assessment methodology to determine sediment quality at two 303(d)-listed sites. The narrative assessment that both sites remain impaired and the identification of a contamination gradient within the channels demonstrate that the methodology is sensitive as well as objective. The assessment framework could be applied at other 303(d)-listed sites within the Bay to evaluate if management actions have reduced the extent of contamination over time.

References

Anderson, B., Hunt, J., Phillips B., Thompson, B., Lowe, S., Taberski, K., Carr R.S. 2007. Patterns and trends in sediment toxicity in the San Francisco Estuary. *Environmental Research* 105: 145-155.

Barnett, A.M, Bay S.M., Ritter K.J., Moore, S.L., Weisberg, S.B. Jan 2008. Sediment Quality in California Bays and Estuaries. Southern California Coastal Water Research Project. Technical Report 522. Costa Mesa, CA.

Battelle Memorial Institute. Nov 2002. Sediment Investigations at Islais Creek and Mission Creek 1998-1999-2000. Prepared for City and County of San Francisco Public Utilities Commission. Carlsbad, CA

Bay, S.M., Ritter, K.J., Vidal-Dorsch, D.E., Field, L.J. 2012. Comparison of National and Regional Sediment Quality Guidelines for Classifying Sediment Toxicity in California. Integrated Environmental Assessment and Management 8: 597-609.

Bay, S.M., Weisberg, S.B. 2012. Framework for Interpreting Sediment Quality Triad Data. Integrated Environmental Assessment and Management 8: 589-596.

Beegan, C., Bay, S.M. 2012. Transitioning Sediment Quality Assessment into Regulations: Challenges and Solutions in Implementing California's Sediment Quality Objectives. Integrated Environmental Assessment and Management 8: 586-588.

Daum, T., Lowe, S., Bartow, G.B., Fairey, R., Anderson, J., Jones, J. Sept 2000. Sediment Contamination in San Leandro Bay, CA. RMP Publication, No. 48. Oakland, CA.

Greenstein, D.J., Bay, S.M. 2012. Selection of Methods for Assessing Sediment Toxicity in California Bays and Estuaries. Integrated Environmental Assessment and Management 8: 625-637.

Hunt, J.W., Anderson, B.S., Phillips, B.M. Newman, J., Tjeerdema, R.S., Taberski, K., Wilson, C.J., Stephenson, M., Puckett, H.M., Fairey, R., Oakden, J. Aug 1998. Sediment Quality and Biological Effects in San Francisco Bay. Bay Protection and Toxic Cleanup Program. Final Technical Report.

Long, E.R., Chapman, P.M. 1985. A Sediment Quality Triad-Measures of Sediment Contamination, Toxicity, and Infaunal Community Composition in Puget Sound. Marine Pollution Bulletin 16: 405-415.

Phillips, B.M., Anderson, B., Lowe, S., Hunt J. 2008. RMP Sediment TIE Study 2007-2008: Using Toxicity Identification Evaluation (TIE) Methods to Investigate Causes of Sediment Toxicity to Amphipods. RMP Publication, No. 561. Oakland, CA.

Phillips, B., Anderson, B., Lowe, S. Dec 2011. RMP Sediment Toxicity Study 2009-2010: Determining Causes of Sediment Toxicity in the San Francisco Estuary. RMP Publication, No. 626. Oakland, CA.

Ritter, K.J., Bay, S.M., Smith, R.W., Vidal-Dorsch, D.E., Field, L.J. 2012. Development and Evaluation of Sediment Quality Guidelines Based on Benthic Macrofauna Responses. Integrated Environmental Assessment and Management 8: 610-624.

Thompson, B., Anderson, B., Hunt, J., Taberski, K., Phillips, B. 1999. Relationships between Sediment Contamination and Toxicity in San Francisco Bay. Marine Environmental Research 48: 285-309.

Thompson, B., Lowe, S. June 2008. Sediment Quality Assessments in the San Francisco Estuary. RMP Publication No. 574. Oakland, CA.

Appendix

Trace Elements						
Station Code	Station Name	Cadmium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Mercury (mg/kg)	Zinc (mg/kg)
21030	Mission Creek (upper-gradient)	3.1	210	380	1.9	620
21301	Mission Creek (mid-gradient)	1.1	91	89	0.57	220
21302	Mission Creek (end-gradient)	0.31	56	31	0.24	130
21027	San Leandro (upper-gradient)	1.5	92	110	0.90	360
E2G	San Leandro (mid-gradient)	0.92	82	64	0.98	230
21313	San Leandro (end-gradient)	0.63	50	47	1.3	160

Bold type indicates concentrations above the ERM value

Polycyclic Aromatic Hydrocarbons (PAHs)			
Station Code	Station Name	Low molecular weight PAHs (ug/kg)	High molecular weight PAHs (ug/kg)
21030	Mission Creek (upper-gradient)	2,200	9,500
21301	Mission Creek (mid-gradient)	840	4,200
21302	Mission Creek (end-gradient)	520	2,200
21027	San Leandro (upper-gradient)	650	3,800
E2G	San Leandro (mid-gradient)	270	1,300
21313	San Leandro (end-gradient)	310	1,400

Polychlorinated Biphenyls (PCBs)		
Station Code	Station Name	PCBs (ug/kg)
21030	Mission Creek (upper-gradient)	510
21301	Mission Creek (mid-gradient)	140
21302	Mission Creek (end-gradient)	13
21027	San Leandro (upper-gradient)	100
E2G	San Leandro (mid-gradient)	56
21313	San Leandro (end-gradient)	170

Organochlorine Pesticides								
Station Code	Station Name	Alpha Chlordane (ug/kg)	Gamma Chlordane (ug/kg)	Dieldrin (ug/kg)	Trans Nonachlor (ug/kg)	DDD's, total (ug/kg)	DDE's, total (ug/kg)	2,4'-DDT (ug/kg)
21030	Mission Creek (upper-gradient)	21	28	4.7	15	43	16	4.2
21301	Mission Creek (mid-gradient)	4.0	6.1	0.73	2.6	12	5.4	2.8
21302	Mission Creek (end-gradient)	0.23	0.32	0.11	0.16	2.4	1.9	0.27
21027	San Leandro (upper-gradient)	12	15	7.1	12	58	30	2.9
E2G	San Leandro (mid-gradient)	1.7	2.0	0.91	1.6	6.7	5.1	0.30
21313	San Leandro (end-gradient)	0.60	0.86	0.33	0.60	3.5	2.8	1.1

Bold type indicates concentrations above the ERM value (chlordane values were bolded if the sum of alpha and gamma chlordane was above 6 ug/kg (ERM for Total Chlordanes). Total DDT (2,4'-DDT and 4,4'-DDT) concentrations were not calculated because 4,4'-DDT values were rejected.

LPAH, HPAH, PCB Sums (SFEI) ^a				
Station Code	Site Name	Low molecular weight PAHs (ug/kg)	High molecular weight PAHs (ug/kg)	Sum of 40 PCBs (ug/kg)
21030	Mission Creek (upper-gradient)	2,300	13,000	920
21301	Mission Creek (mid-gradient)	910	6,000	270
21302	Mission Creek (end-gradient)	570	3,000	22
21027	San Leandro (upper-gradient)	720	5,400	170
E2G	San Leandro (mid-gradient)	290	2,000	93
21313	San Leandro (end-gradient)	340	2,100	76

^aSFEI's PCB, LPAH, and HPAH sums differ from those used in the SQOs. For informational purposes, the above table lists concentrations for SFEI specific sums. SFEI's analyte list can be found here: <http://www.sfei.org/rmp/data/TargetAnalyteList>.

Bold type indicates concentrations above the ERM value

Benthic Indices					
Station Code	Site Name	BRI	RBI	IBI	RIVPACS
21030	Mission Creek (upper-gradient)	60 (3)	0.08 (4)	2 (2)	0.16 (3)
21301	Mission Creek (mid-gradient)	44.01 (3)	0.07 (4)	2 (2)	0.16 (3)
21302	Mission Creek (end-gradient)	23.23 (2)	0.25 (3)	1 (1)	0.27(3)
21027	San Leandro (upper-gradient)	44.15 (3)	0.22 (3)	2 (2)	0.34(2)
E2G	San Leandro (mid-gradient)	43.93 (3)	0.11(4)	1 (1)	0.40 (2)
21313	San Leandro (end-gradient)	51.05 (3)	0.16 (4)	0 (1)	0.51 (2)

Numbers in parenthesis indicate category score (from 1 to 4)