Sediment Quality Assessments in the San Francisco Estuary

by

Bruce Thompson and Sarah Lowe

San Francisco Estuary Institute

and the Regional Monitoring Program

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SAN FRANCISCO ESTUARY INSTITUTE

7770 Pardee Lane, Second floor, Oakland, CA 94621

p: 510-746-7334 (SFEI), f: 510-746-7300, www.sfei.org

EXECUTIVE SUMMARY

Sediment Quality Objectives (SQOs) for California Bays and Estuaries provide a new framework and methods for assessment of sediment condition in San Francisco Estuary. The SQO assessment methods were recently applied to a limited number of stratified, probabilistically sampled sites from the EMAP 2000 study in the San Francisco Estuary as part of a statewide sediment assessment. The objectives of this report are to expand the sediment assessments in San Francisco Estuary to include additional samples from the RMP and the Bay Protection and Toxic Cleanup Program (BPTCP), compare the results from the statewide assessment with these additional assessments, evaluate the relationships between the chemical, toxicity, and benthic indicators and lines of evidence (LOEs) used in the SQO assessments, and conduct preliminary stressor identification evaluations to identify contaminant associated with the observed SQO impacts.

The SQO framework and methods are summarized, as well as the results from the statewide assessment in the Estuary. Results from additional sediment assessments at seven RMP sites samples over seven years (66 samples) and from one BPTCP sample collected in San Leandro Bay in 1997 are reported. The RMP sites had incidence of impacts ranging from 80% at Redwood Creek (BA41) to none in Horseshoe Bay (BC21), showing variation in impacts over time at most sites. These variations probably reflect changes in sediment conditions related to changes in annual and seasonal differences in run-off, salinity, and contaminant loadings. The results of the assessments were consistent with RMP sediment evaluations that have been conducted for over a decade. Assessments at 40 EMAP-NOAA 2000 sites used in the statewide assessment report showed a considerably higher average incidence of sediment impact (95% of the samples) than in the RMP / BPTCP samples (38.8%). The use of a single toxicity test in the statewide assessment, the fact that the EMAP samples were collected in 2000, following five years of above average runoff, and differences in sample design between the RMP and EMAP surveys, may account for these differences.

Stressor identification evaluations for toxicity and benthic disturbance associated different contaminants with those impacts at different RMP sites. Toxicity was associated with low molecular weight polyaromatic hydrocarbons (LPAHs) at the Alameda site and DDTs at Yerba Buena Is. site. Benthic disturbance was associated with LPAHs, dieldrin and polychlorinated biphenyls (PCBs) at the South Bay site, and HPAHs at Redwood Creek. There were no widespread or obvious patterns within the EMAP samples.

The SQO indicators and assessment framework provided a technically sound and consistent basis for assessing sediment condition in San Francisco Estuary. Several recommendations for the continued refinement and application of the SQOs include:

1. Validate the chemistry indicator, *Chemical Score Index* (CSI) using San Francisco Estuary data.
2. Decide which bivalve sediment toxicity tests should be used in San Francisco Estuary.
3. Evaluate benthic indices for use in the mesohaline (estuarine), and other habitats.
4. Expand the list of contaminants included in the chemistry indicators (only five trace elements and eleven organic contaminants were used).
5. Continue to develop stressor identification methods to determine cause and effect for observed toxicity and benthic disturbance.

Some of these recommendations are planned for inclusion in SQO Phase 2 currently underway in the Delta. Others are included in the RMP Exposure and Effects Work Group five-year plan.

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INTRODUCTION

Sediment Quality Objectives (SQOs) for California Bays and Estuaries provide a new framework for assessment of sediment condition in San Francisco Estuary (SWRCB, 2007). The SQO assessment methods are based on the familiar sediment quality triad approach (e.g. Chapman, 1996), and include indicators of sediment contamination, sediment toxicity, and benthic macrofauna. Although the Regional Monitoring Program (RMP) has conducted similar multi-metric sediment assessments since 1993, the methods used for SQOs include standardized, structured, peer-reviewed indicators that will be used to assess and regulate sediment quality.

The SQOs framework and indicators were recently applied in a statewide assessment of estuary sediment condition (Barnett *et al*., 2007). That study provided a first-of-its-kind comparison of northern California estuaries, San Francisco Estuary, and southern California estuaries. The statewide study used a limited number of samples that were collected from Generalized Random Tessellation Stratified (GRTS) sampling designs in order to assess sediment condition on an area basis. In San Francisco Estuary, samples from the USEPA's Environmental Monitoring and Assessment Program (EMAP) survey in 2000 were used. Samples from the RMP's Status and Trends sampling design (fixed stations along the spine of the Estuary) and Benthic Pilot Study (1994-2001) were not included in the statewide assessments. Therefore, additional sediment assessments were conducted and the results are presented in this report. The objectives of this study were to:

1. Expand the sediment assessments in San Francisco Estuary to include additional samples from the RMP and the Bay Protection and Toxic Cleanup Program (BPTCP) collected between 1994-1997.
2. Compare the results from the statewide assessment with these additional assessments, to evaluate the relationships between the chemical, toxicity, and benthic indicators and lines of evidence (LOEs) used in the SQO assessments.
3. Conduct analyses of possible contaminant drivers for observed SQO impacts.

The information in this report will facilitate the understanding of how the SQO assessment methods work, and enhance the context for interpretation of the SQO assessment results.

Conceptual models of contaminated sediment effects

The SQO Staff Report (SWRCB, 2007) includes a section on conceptual models of sediment quality impacts. Additional considerations include the expected responses of sediment toxicity tests and benthic organisms to sediment contamination gradients.

Toxicology dose-response models for single contaminants from laboratory studies usually show logistic response curves of increasing toxicity with increased contaminant concentrations; often a toxicity threshold (i.e. NOEC, LC50) may be derived (Landis and Yu, 2004). Mixtures of sediment contaminants commonly found in estuary sediments usually show increased toxicity at increased concentrations (Long *et al*., 1998).

Models of sediment effects on various benthic indicators have been published for increases in organic material (Pearson and Rosenberg, 1978), and modified for sediment contaminant mixtures (Thompson and Lowe, 2004). These models suggest that benthic indicator metrics (e.g. abundances of sensitive taxa, total abundances, etc) have non-

linear responses to increases in organic material, or contamination, characterized by increased values at intermediate contaminant or organic material concentrations, and complete mortality at extremely high concentrations. Reponses of multimetric benthic indices, as SQO indicators, produce more linear responses to concentration gradients, because they average the response of many metrics.

Conceptually, there is no reason to expect that toxicity and benthos should be correlated, except when both are severe. The two indicators are intended to measure different kinds of biotic responses. Toxicity tests are conducted in the laboratory, measure acute response of generally sensitive animals that may not be resident species in the habitats assessed. Benthic assessments reflect time-integrated exposures to 'disturbances', and measure sublethal changes in abundances of sensitive and tolerant organisms, and include measurements of population and community structure. The SQO methods use three LOEs because we do not understand enough about cause and effect in any one of them. Thus, the toxic and benthic components of framework are intended to be evaluated as independent measurements of sediment condition.

METHODS

The SWRCB's Staff Report includes a description of the SQO framework and indicators, as well as regulatory considerations (SWRCB, 2007, and Appendices A,B,C). The details for the Staff Report are included in a series of technical reports and publications (Bay *et al.* 2007a,b,c,d; Ranasinghe *et al*., 2007a,b; Ritter *et al.*, 2007; Weisberg *et al*. 2008). The SQO methods are briefly summarized below to facilitate the understanding of this report.

The data used in development and testing of the SQO indicators include numerous samples collected from California Coastal Bays and Estuaries. The data were rigorously evaluated for quality assurance, and standardized for statewide use. The SQO indicators and evaluation used in the statewide assessment (Barnett, *et al.* 2007) and in this report were identical, so that the results are comparable.

SQO Framework

The SQO framework uses the sediment quality triad concept of multiple lines of evidence based on measurements of sediment contamination (chemistry), sediment toxicity tests, and benthic macrofaunal assessments. These lines of evidence (LOEs) provide a weight-of-evidence for sediment condition. Three LOEs are used because no single LOE alone provides adequate information to evaluate sediment condition (SWRCB, 2007).

Application of the SQO framework involves using a prescribed set of steps to evaluate each LOE, and combine them into an overall SQO assessment (SWCRB, 2007 Appendix C). Each of the three LOEs includes several different indicators or indices for the respective LOE (described below). Each indicator provides an indicator score, which is placed into one of four categories of impact. The indicator categorie(s) are combined into a LOE category of impact (Table 1).

Table 1. Lines of Evidence (LOEs) and category scores used in the SQO assessments

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

The three LOE category scores provide multiple lines of evidence (MLOE) that are combined into a final SQO site assessment (called the SQO score in this report), and a narrative, in one of five SQO assessment categories, or scores (Bay and Weisberg, 2007):

Score	Narrative
1	Unimpacted
2	Likely unimpacted
3	Possibly impacted
4	Likely impacted
5	Clearly impacted

For the assessments, a LOE category or SQO score of 2 was the threshold for 'impacts'; categories or scores of 3 or more were considered to indicate levels of impacts shown above and on Table 1. An assessment may be considered "Inconclusive" if there is inadequate data for completion of the assessment.

Chemistry Indicators

Sediment contamination was evaluated using 17 of commonly collected trace metals and organic compounds (Table 2). Two chemistry indicators were developed for the SQO assessments: 1) The California Logistic Regression Model (CA LRM) is based on logistic regression methods for estimating the probability of toxicity of individual contaminants. The maximum probability *(p value)* for the chemicals evaluated is termed the LRM (Bay *et al*., 2007). 2) The Chemical Score Index (CSI) was developed using apparent thresholds of impacts on Southern California benthic responses (Ritter *et al*., 2007). Both indicators produce scores that are placed into one of four categories of exposure that were determined statistically. The two indicator categories were then combined into an overall Chemistry LOE category.

Table 2. Sediment contaminants used in the SQO assessments

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

Toxicity Indicators

The SWRCB Staff Report (2007) recommends 5 toxicity tests that are believed to provide the best assessment results. The SQO assessment method recommends the use of 2 sediment toxicity tests, one with acute endpoints (survival), and another with sub-lethal endpoints (e.g. growth, development: Bay *et al*., 2007). The statewide assessment used the *Eohausorius estuarius* (amphipod) test, because it was the only test commonly used in all regions of the state considered. No sub-lethal test was included in that assessment. The mean percent survival from the *E. estuarius* test was normalized to the control survival rate, then the percent control survival (score) was divided into four toxicity LOE categories. Methods are prescribed for combining categories from multiple toxicity tests into an overall toxicity LOE (Bay *et al.,* 2007).

Benthic Indicators

Four benthic indices are recommended for use in the SQO assessments for Enclosed Bays and Estuaries: Benthic Response Index (BRI), Index of Benthic Integrity (IBI), Relative Benthic Index (RBI), and River Invertebrate Prediction and Classification System (RIVPACS). Each index was independently derived and tested, and includes several benthic metrics. A combination of all four indices was shown to predict benthic disturbance in bay habitats better than any single index alone (Ranasinghe, *et al.*, 2007a).

Benthic assessments are developed and applied differently in different habitats (benthic assemblages), each employing habitat-specific benthic metrics. Assessments have been developed for only two habitats: polyhaline, or bay habitats where salinities are highest, and mesohaline, or estuarine habitats where salinities are moderate and more variable. The San Francisco Estuary benthic assemblages were identified using multivariate classification and ordination methods (Thompson, *et al.,* 2000; Ransinghe *et al*. 2007b). The statewide assessment included benthic assessments of both of these habitats in the Estuary. However, only two indices, the IBI and RBI, have been developed for the estuarine habitat. The formulations for these indices have not been reviewed and tested to the same extent as for the bay habitat.

Each benthic index is calculated as an indicator score; the BRI is continuous between 0-100, IBI is a categorical (4 - 5 impact categories), RBI is inversely scaled where the lowest score equals highest impacts, and RIVPACS is a non-linear distribution. The index scores are placed into one of four categories of impact (Ranasinghe *et al*. 2007a); the categories were determined separately for each index. The index categories are combined to produce an overall benthic LOE category for each sample.

RMP and BPTCP Assessments

Sixty-seven samples collected in San Francisco Estuary were assessed: 66 samples from seven RMP sites and one BPTCP sample from San Leandro Bay (Figure 1, Table 3). Three of the RMP sites were from bay habitats, two sites switched habitat-type over time due to seasonal salinity changes, and two sites were from estuarine habitats. Only sites that met SQO acceptance criteria (three LOEs, QAQC, etc.), and that were not used for SQO method development were used in this analysis. The RMP samples were screened along with EMAP samples used in the statewide assessment, and the LOE indicators and indices scores and LOE categories were calculated at the same time as those used in the statewide assessment report. Thus, the results are directly comparable. Other RMP stations were not included because they were either used in development of the SQO indicators and indices, or they did not meet data inclusion criteria.

Unlike the EMAP-2000 assessment, which only used the amphipod survival toxicity tests, the RMP assessments include a second sub-lethal toxicity test as recommended by the SQO assessment methodology. The RMP has used the bivalve (mussel or oyster) larval development test on sediment elutriates since 1993 and it has been used to interpret patterns and trends sediment toxicity in the region. However, the elutriate test is not among the tests recommended for use in the SQO assessments (Bay *et al*. 2007c). A different version of that test, using bivalve larvae exposed to intact sediment cores is recommended. Comparisons of the elutriate and intact core tests in San Francisco Estuary have shown that the two tests produce similar results (B. Anderson, UC Davis; personal communication).

Both the *Eohaustorius* and bivalve elutriate test were used in the SQO assessments at the RMP sites in this report, to evaluate how the inclusion of a second toxicity test might influence the overall assessment results. The toxicity LOE thresholds and categories derived for the SWI tests (Bay *et al*., 2007c) were applied to the RMP elutriate test results.

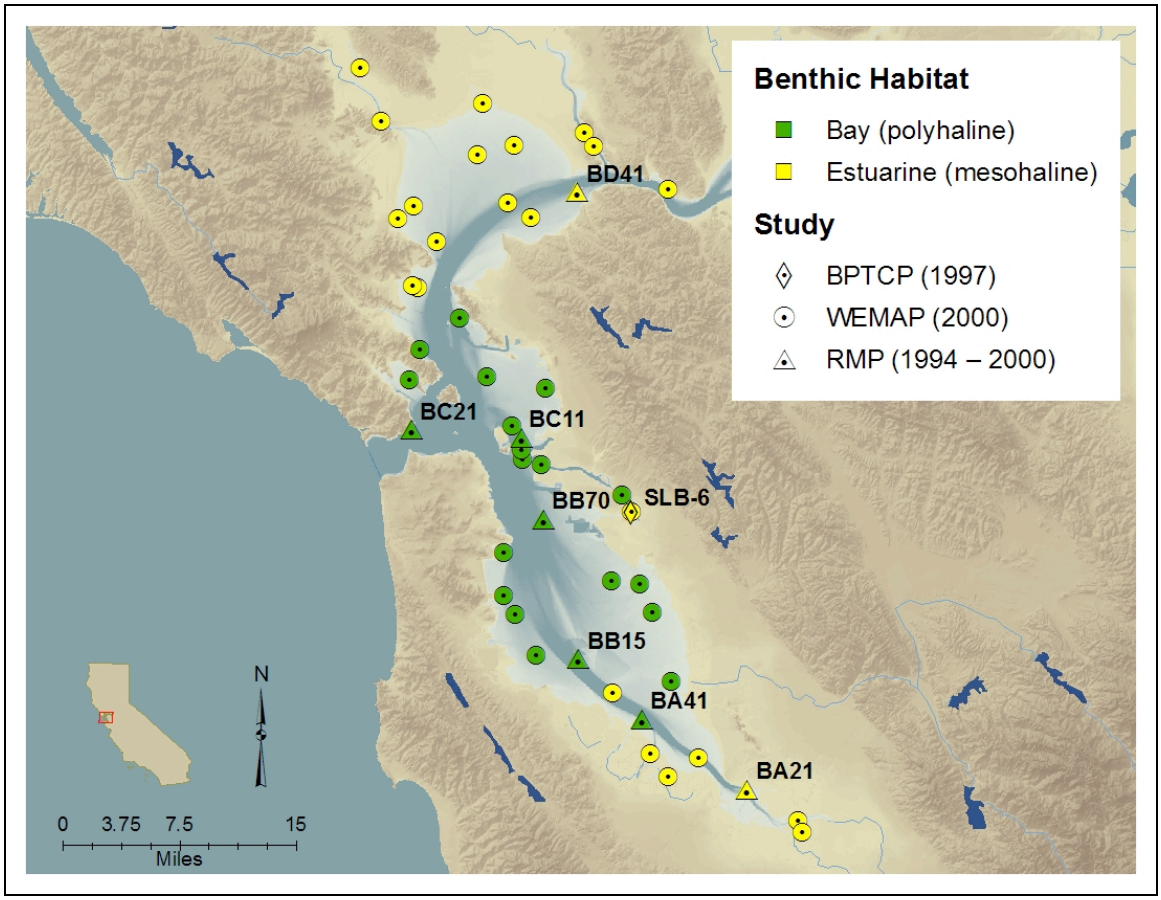

Figure 1. Map of stations included in this report, showing sites used in the statewide assessment in San Francisco Bay (EMAP, 2000; n=40) and the RMP sites (n=7) and BPTCP (n=1) sites.

Relationships among SQO indicators and LOEs

The SQO methods use several new indicators, indices, and assessment categories. The relationships among these components have not been presented for the San Francisco Estuary. In order to understand the SQO results in more detail, and have some level of comfort with the assessment findings, analyses are presented in this report that begin to investigate these relationships. These analyses were conducted at two levels:

1) Using the actual indicator scores: chemistry index (CA LRM and CSI), benthic index (BRI, IBI, or RBI), and toxicity result (e.g. amphipod mortality), and

2) Using the resulting chemistry, benthos, and toxicity LOE category scores (1 – 4; see Table-1).

Analyses using indicator scores show relationships between the basic components of the framework, and allow for an evaluation of how well they fit our conceptual models. Using the LOE category scores presents the relationships between these components within the SQO framework. These analyses were conducted using nonparametric Spearman's rank correlations, which provide an indication of the level of concordance between the variables.

Stressor Identification

The SQO indicators were not designed to identify the cause(s) of observed impacts. The indicators assess sediment condition and show the relative severity of impacts. The SQO Water Quality Plan (Appendix A, 2007) recommends that when impacts are identified, "stressor identification" studies should be conducted to attempt to identify the causes. Although the chemistry indices used in SQO assessments include intermediate steps that identify thresholds of effects for individual contaminants, stressor identifications should not employ these effects levels because they are not intended to identify individual contaminant drivers.

Determining which sediment contaminants may be causing sediment impacts identified by an SQO assessment is very difficult because the different indices for each LOE (or their individual metrics) may each be influenced by different contaminants, or even by other non-anthropogenic factors. Environmental sediment samples contain mixtures of contaminants and the synergistic effects of contaminant mixtures are poorly understood. The conceptual models described in the Introduction provide a framework for interpreting the possible pollutant drivers of impacts. Correlations between toxicity, benthic disturbance, and contamination may show associations, but should not be interpreted as cause and effect.

Differences in location should also be considered. In the Estuary, regional hydrodynamic processes, contaminant sources and loadings, and resulting distribution of sediment grain-size may affect sediment contamination and biological effects. Sediment patterns in the South Bay are very different from those in Central, or San Pablo Bays. Patterns in enclosed embayments, or near the Estuary margin are different from those in the deeper, main channels. Pooling data across those locations tends to obscure regionally important patterns that may relate to toxicity or benthic disturbance.

This report takes a preliminary step towards such identifications using the information available from the SQO database. Spearman's rank correlations and co-occurrences are used to evaluate whether there were any obvious relationships between

contamination and impacts at each RMP site over time and at the EMAP sites. Sediment contaminant concentrations at impacted sites were also compared to the Effects Range Median, and Effects Range Low (ERM, ERL) sediment quality guidelines and mean ERM quotient (mERMq, Long *et al*., 1998). The RMP has used the Effects Range guidelines for many years to evaluate relative sediment condition in the Estuary along with incidence of toxicity (e.g. SFEI, 2007). The ERL guideline is not very well associated with sediment toxicity, but the ERM guideline is considered to be a good predictor of toxicity. Two mERMq effects thresholds were used: values above 0.185 were associated with a higher than 65% incidence of toxicity (Thompson *et al*. 1999), and mERMq above 0.147 was associated with a higher than 85% incidence of benthic impacts (Thompson and Lowe, 2004). The use of these guidelines to evaluate the SQO assessment results facilitates interpretation of the SQO results and provides a connection to past RMP sediment evaluations.

RESULTS AND DISCUSSION

Summary of the Statewide Assessment Results in San Francisco Estuary

The statewide assessment included 40 random samples collected from San Francisco Estuary by the EMAP survey in 2000. These samples were collected from bay (polyhaline) and estuarine (mesohaline) habitats (Figure 1). The region was also divided to include strata for ports and marinas.

Overall, 98% of the sediments in the two habitats were considered to be in "Poor" condition (SQO Score > 2), with 91% of the bay habitats as Poor, and 99.2% of the Estuarine sites as Poor. Only two of the 40 samples assessed were in "Good" condition (SQO Score ≤ 2; see Table 1.c in Appendix 1).

The toxicity LOE appeared to drive the results; 82% of the samples had toxicity LOE categories of 3 or 4 (moderate or high toxicity). Benthic LOE categories were 3 or 4 (moderate or high disturbance) in 42.5% of the samples, and chemistry LOEs were 3 or 4 (moderate or high exposure) at 50% of the samples.

Although sediment toxicity has been characterized as widespread and persistent in the Estuary (Anderson *et al.* 2007), the incidence of *Eohaustorius* toxicity reported in the EMAP samples was considerably higher than previously reported. Possible reasons for these differences are discussed in the *Comparison of RMP and EMAP assessment results* section below.

Table 3. Summary of SQO Statewide Assessment Results for San Francisco Estuary. Good = SQO Scores 1, 2 and 'Poor' = SQO Scores >2.

SF Estuary Stratum	Sample n	SQO Category	% Area Estimate	Lower, Upper Conf. limits	% Area
Bay	11	Poor	91.0	75.7	100.0
Bay	1	Good	9.0	0.0	24.3
Estuarine	20	Poor	99.2	97.8	100.0
Estuarine	1	Good	0.8	0.0	2.2
Marina	1	Poor	NA	NA	NA
Marina	0	Good	NA	NA	NA
Port	6	Poor	100	100	100
Port	0	Good	NA	NA	NA

Adapted from Barnett *et al*., 2007

Assessment of RMP and BPTCP sites

The results of the SQO assessments for the RMP and BPTCP sites are expressed as incidence of impacts at the sample level (percent of occurrence), in contrast to the the statewide assessment, which expressed results as percentage of geographic area impacted. The RMP and BPTCP samples were not collected using a randomized probabilistic sampling design, and therefore the results cannot be extrapolated to geographic area. Additionally, the RMP / BPTCP samples were assessed using two toxicity tests as described in the Methods.

Of the 67 RMP and BPTCP samples assessed, 38.8% were classified as impacted (SQO Score > 2; similar to the "Poor" category used in the statewide assessment; see Table 2.c in Appendix 1). The chemistry LOE showed moderate to high exposure (LOE=2, 3) in 38.8% of the samples, the toxicity was moderate to high (LOE=3,4) in 28.4% of the samples (Table 2.b in Appendix 1), and benthic disturbance was moderate to high (LOE=3,4) in 23.9% of the samples (Table 2.a in Appendix 1). The incidence of impact (SQO Score > 2) at the seven RMP sites ranged between 0 and 80%, with three sites having at least half of the samples impacted (Table 4).

Table 4. Results of SQO Assessments for the RMP and BPTCP Sites, 1994-2000. B = Bay habitat; E = Estuarine habitat.

Location	Sta. ID	Habitat	n	% Impact
South Bay	BA21	E	10	60
Redwood Creek	BA41	B,E	10	80
San Bruno Shoal	BB15	B,E	9	33.3
Alameda	BB70	B	10	50
Yerba Buena Is.	BC11	B	10	20
Horseshoe Bay	BC21	B	10	0
San Leandro Bay	SLB6	E	1	
San Pablo Bay	BD41	E	7	14.3
		Totals	67	
		Bay	44	
		Estuarine	23	

The BPTCP study sampled five sites in San Leandro Bay in April 1997. However, only one of those samples was included in this analysis (SLB-6), and it was assessed as 'clearly impacted' (SQO Score=5). All three LOE categories were above impact thresholds.

The RMP South Bay site (BA21) is located in the lower South Bay near the deep channel of the Estuary, where several significant tributaries drain (i.e. Coyote Creek, Guadalupe River, and Alviso Slough, Figure 2). Ten samples from the wet and/or dry season, 1994 to 2000, were analyzed. This site is part of the estuarine habitat. Six of the ten samples assessed had a SQO Score of 3 or 4 (possibly impacted or likely impacted: Figure 2 and Table 2.c in Appendix 1). There was no clear seasonal pattern in the SQO scores over time. In 1995 and 1997, the years with the highest storm water runoff, both the winter and summer assessments showed SQO scores of 2 and 1 (likely unimpacted and unimpacted). The chemistry and toxicity appeared to be the drivers of the

assessments at this site. Chemistry LOEs were above thresholds (LOE>2) in all samples, and toxicity was above the threshold in half the samples (Appendix 1).

The RMP Redwood Creek site (BA41) is located in the South Bay near the mouth of Redwood Creek (Figure 2). Ten samples from the wet and/or dry season, 1994 to 2000, were analyzed. This site is usually part of the bay habitat, but during 1997, a high rainfall year, the benthic community changed to an estuarine habitat. Eight of the ten samples were possibly impacted or likely impacted (SQO Scores >2; Figure 2 and Table 2.c in Appendix 1). There was no clear seasonal pattern in the scores, but the two unimpacted samples (SQO Score = 2) occurred during the wet season. There was no difference in the SQO Scores associated with the change in habitat-type in 1997. Impacts in all three LOEs contributed to the assessments at this site with at least one moderate LOE score (category score of 3) in all samples (Appendix 1, Tables 2a-c).

The RMP site at San Bruno Shoal (BB15), is located in the South Bay region of the Estuary in the deep channel, south of a shallow oyster shell bed (Figure 2). Nine samples from the wet and/or dry season, 1994 to 2000, were analyzed. This site experienced shifts in benthic habitat-type during that time period, with three of the samples classified in the Estuary habitat (Figure 2). Three of the nine samples were impacted. The samples collected between 1995 and 1997 were not impacted. But, the samples collected between 1998 and 2000 were impacted. Sediment chemistry appeared to drive the assessments in February 1998, and both chemistry and benthic disturbance drove the results in August 1998 and 2000 (Tables 2.a-c in Appendix 1).

The RMP Alameda site (BB70), is located in the Central Bay main channel, west of Alameda (Figure 1). Ten samples from the wet and/or dry season, 1994 to 2000, were analyzed. These samples were consistently classified as bay habitat. Five of the 10 samples were assessed impacted (SQO Score>2; Figure 2 and Table 2.c in Appendix 1). Different LOEs appeared to drive the assessments in the samples over time. Toxicity was 'high' in 1994, but chemistry appeared to drive the assessments in the dry seasons of 1995, 1998 and 2000, and benthos drove the assessment in February 1997 (Tables 2.a-c in Appendix 1).

The RMP Yerba Buena Island site (BC11) is located in the Central Bay, east of Treasure Island (Figure 2). Ten samples from the wet and/or dry season, 1994 to 2000, were analyzed. This site was classified as bay habitat. Only two dry season samples from this site were assessed as impacted (Figure 2). Toxicity appeared to drive the assessments at this site with moderate to high toxicity category scores in all dry season samples (Tables 2.a-c in Appendix 1).

The RMP Horseshoe Bay site (BC21) is located in the Central Bay Region of the Estuary near the north side of the Golden Gate Bridge (Figure 2). Ten samples from the wet and/or dry season, 1994 to 2000, were analyzed. This region of the Estuary is dominated by oceanic water, but was classified as bay habitat. Probably as a result of the oceanic influence and rather coarse sediments at this site, all ten samples were assessed as unimpacted (SQO Scores of 1 or 2; Figure 2 and Table 2.c in Appendix 1).

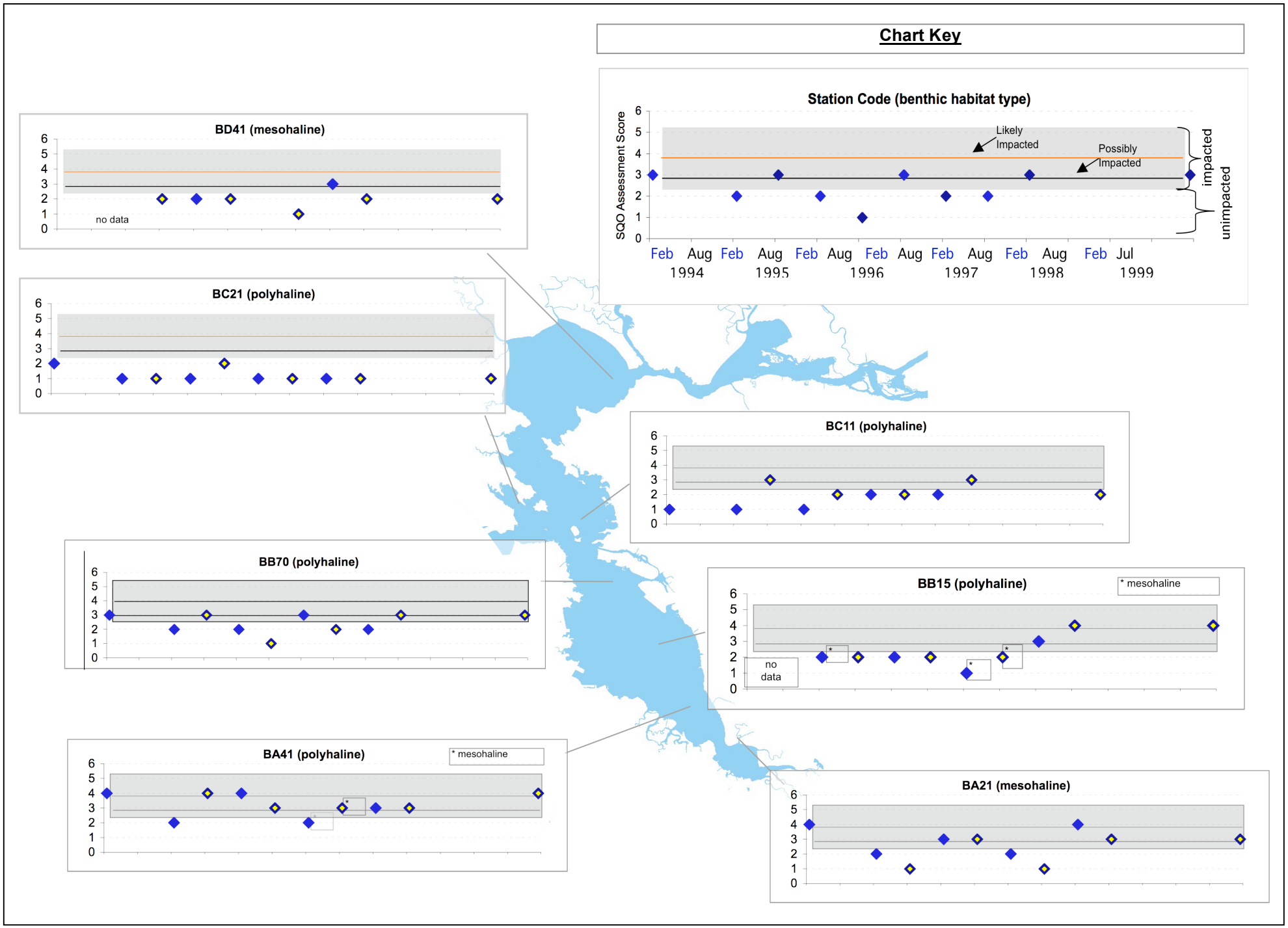

Figure 2. SQO Assessment scores at seven RMP sites sampled between 1994 and 2001

The RMP San Pablo Bay station (BD41) is located in the San Pablo north of the Richmond Bridge (Figure 2). Seven samples from the wet and/or dry season, 1994 to 2000, were analyzed. This region of the Estuary is dominated by Delta outflow from the Sacramento and San Joaquin Rivers and other major North Bay tributaries (Sonoma Creek, Petaluma, and Napa Rivers). It was classified as estuarine habitat. Only one of the seven samples was assessed as possibly impacted (February 1998; Figure 2). Sediment toxicity drove the assessment in that sample, but the benthic LOE was above the threshold in five of the samples (Tables 2.a-c in Appendix 1).

Overall, three of the RMP sites, Redwood Creek (BA41) and South Bay (BA21), and Alameda (BB70), had sediment impacts in at least half of the samples over time; Horseshoe Bay (BC21) was never impacted. The incidence of sediment impacts was comparable in the bay and estuarine habitats, but the incidence of toxicity and benthic disturbance were clearly higher in the estuarine samples (Table 5). However, the magnitude of toxicity in both the amphipod survival and bivalve development tests were not significantly different between the two habitats (Wilcoxon 2-sample test, $p>0.05$).

Table 5. Comparisons of the incidence of impacts (% of samples with SQO Score > 2) between habitats and seasons in the RMP and BPTCP samples.

	n	SQO Score	Tox LOE	Ben LOE	Chem LOE
Habitat					
Bay	44	38.6	22.7	18.2	31.8
Estuarine	23	39.1	39.1	34.8	39.7
Season					
Wet	32	34.4	25.0	21.9	37.5
Dry	35	42.9	31.4	25.7	40.0

The incidence of sediment impacts in these samples was higher in the dry season samples than in the wet season samples, but not appreciably. Amphipod survival in wet season samples was significantly lower between 1994-1996 (Thompson *et al.*, 1999), and between 1997-2001 (Anderson *et al*., 2007). The differences between the results shown in Table 10 and those previously reported probably reflect differences in the subsets of RMP data used in those analyses. There was no significant difference in the magnitude of toxicity in the amphipod survival or bivalve development tests between the wet and dry seasons (Wilcoxon 2-sample test, $p>0.05$).

Comparison of RMP and EMAP assessment results

The RMP and EMAP assessment results are only comparable based on the incidence of impacts among the samples because of the differences in design of each program. The RMP and BPTCP assessments showed that 38.8% of the samples were impacted compared to the EMAP samples that had 95% of the samples impacted (Table 6). Additionally, the incidence of moderate to high (LOE categories = 3,4) chemistry exposure, toxicity, and benthic disturbance was consistently greater in the 2000 EMAP samples than in the RMP and BPTCP samples.

Table 6. Comparisons of the incidence of impacts (% of samples with Category Score > 2) between the EMAP and RMP / BPTCP samples. The RMP toxicity assessment used two toxicity tests.

	n	SQO Score	Chem LOE	Tox LOE	BenLOE
EMAP	40	95.0	50.0	82.5	42.5
RMP/BPTCP	67	38.8	38.6	28.4	23.9

The main difference in the results between the two assessments is mostly due to the use of two toxicity tests in the RMP assessment vs. only the amphipod survival test in the EMAP assessment. Using the *Eohaustorius* test alone, the incidence of toxicity in the RMP samples was 54.5%, which is still considerably lower than the incidence in the EMAP samples (82.5%). The inclusion of the bivalve elutriate test in the RMP assessments changed the toxicity LOE category in over half the samples (51.5%), usually improving the LOE category score by 1. Most of the changes in category scores were from a 3 to 2 (moderate- to low toxicity), but in two samples, the category score increased to 3 owing to significant toxicity observed in the bivalve tests.

The use of both toxicity tests also changed the overall SQO Score in the RMP samples. The SQO Scores in 19 of the 67 samples was reduced by 1 category, but the score at one site was increased by 2. Twelve of the 19 changed from a 3 to a 2, reducing the overall assessment to "likely unimpacted".

The *Eohaustorius* test and the bivalve elutriate test measure different aspects of sediment toxicity. The amphipod test uses exposure to bulk sediments and an acute endpoint (survival), and the bivalve test uses exposure to sediment elutriates and a sublethal endpoint (normal development). These two tests often produce opposite toxicity results on the same sample, but that does not mean one test or the other is incorrect. They simply measure different aspects of toxicity. In sediment assessments, this is a desirable quality, so as not to bias the results one way or the other, and is why the SQO methods recommend at least two different kinds of tests with a lethal and sub-lethal endpoint. Thus, when the results of the amphipod and bivalve test were combined in the toxicity LOE, they effectively averaged the toxicity response, and contributed to lower SQO scores, than those using just the amphipod test.

Although using two toxicity tests accounted for a large portion of the difference between the two assessments, there remain unexplained differences in the incidence of impacts between all three LOEs as shown on Table 6. The following three hypotheses are proposed to account for these differences.

1. The 2000 EMAP samples were collected following five years of above average Delta outflow that may have increased contaminant loading to the Estuary resulting in higher incidence of impacts.

Delta outflow (an indicator of increased runoff) was above average between 1995-1999 (Figure 3). The incidence of RMP dry season sediment toxicity also increased between 1995-2000 (Figure 4). In 2000, the incidence of toxicity among the EMAP samples was very high (82.5%), and the incidence of toxicity in the RMP July 2000 samples was the highest dry-season incidence (53.8%) since the inception of the

RMP. The incidence of toxicity among the EMAP samples in 2000 was significantly higher than in the RMP samples from the same time (Wilcoxon, $p < 0.05$). However, sediment contamination did not appear to increase over this same period. The average mERMq in the EMAP samples was higher (0.110) than in the RMP samples (0.072) in 2000 (Figure 4), but there was no significant difference between the two surveys, considering the variability (Wilcoxon, $p > 0.05$). It is possible that other, unmeasured contaminants (especially pesticides) increased during that time period. The difference in mERMq could be related to differences in sediment grain-size between the two surveys. EMAP apparently sampled a higher proportion of sites with fine sediment. The EMAP 2000 samples had mean % fine sediments of 87.7%, compared to the RMP 2000 mean of 64%.

2. Differences in sample design between the EMAP sites (random) compared to the RMP's selected fixed sites, resulted in higher incidence of impacts in the EMAP samples.

The RMP sites used in this assessment were originally located to be "ambient" sites that represented background conditions in the Estuary. They were purposely located in the main channels, or close thereby, to be away from major tributaries, ports, marinas, outfalls, or other sources of contamination. In contrast, the EMAP sites were randomly chosen to provide an unbiased sample of Estuary conditions.

3. There were analytical differences between the EMAP and RMP samples.

The sediment toxicity tests for both studies were conducted by the same laboratory, UC-Davis Marine Pollution Studies Laboratory (UCD-MPSL). The QA/QC results from both studies were within the method quality objectives, indicating that the test conditions and protocols were comparable for both studies. Sediment contamination was analyzed by separate laboratories, but each lab followed similar quality assurance protocols for analysis. However, the sums of some of individual congeners that comprised some of the reported compounds for some of the trace organic contaminants (e.g. Sum of PCBs) were different. However, the SQO team worked hard to standardize data between studies probably making these differences insignificant.

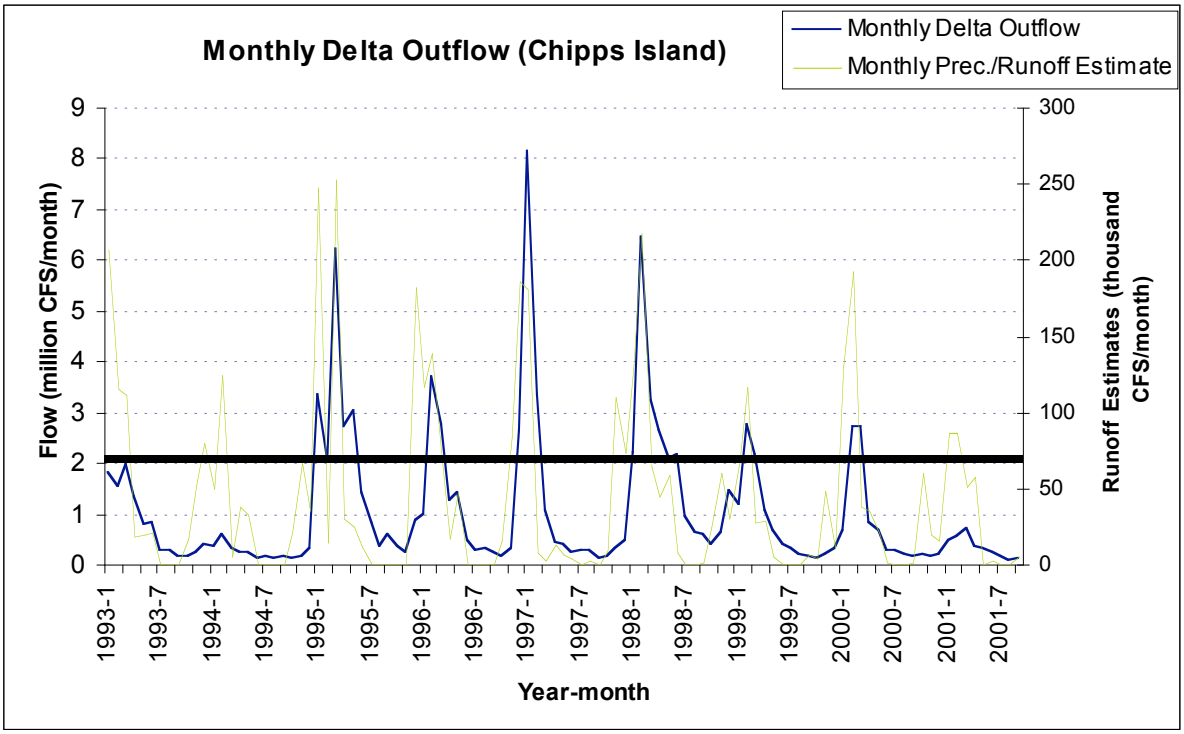

Figure 3. Estimate of Delta Outflow, 1993-2001.
Data from Interagency Ecological Program: http://www.iep.ca.gov/dayflow/index.html.
Heavy horizontal line is 'average' annual Delta outflow.

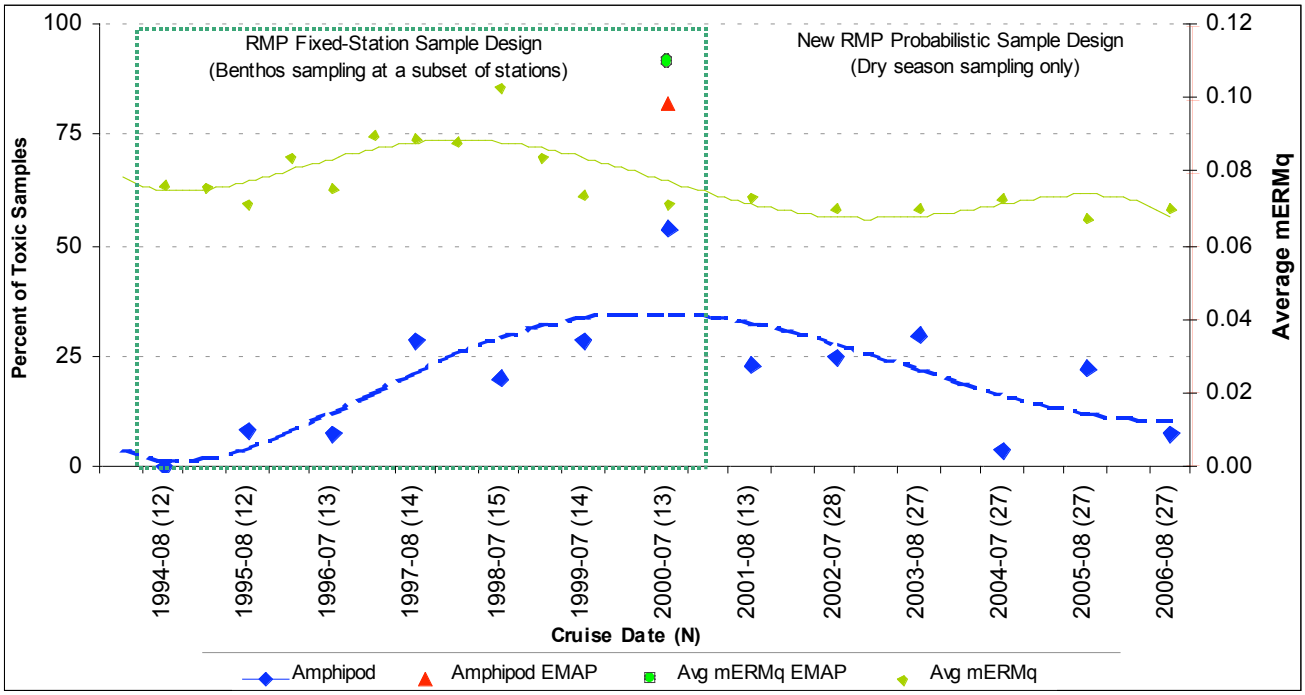

Figure 4. Incidence of dry-season sediment toxicity and comparison of average mERMq values over time in RMP samples (1994-2006) and the EMAP samples (2000; n=40).

Relationships among the SQO indicators, indices, and LOEs

Interpretation of the SQO assessment results is facilitated by an understanding of how the LOEs are composed, how they relate to each other, and by comparisons to other guidelines and thresholds that the RMP has used in the past. For these analyses, the samples from EMAP and RMP / BPTCP were used together. These evaluations were conducted at two levels: 1) using the individual indicator and index scores (e.g. CA LRM, benthic indices, etc.) to evaluate how the SQO components relate to each other, and 2) Using the LOE categories (1-4), to evaluate how well the SQO framework reflects the relationships in 1).

Chemistry indicators

The scores for the two SQO contaminant indicators (CSI, CA LRM), and mERMq previously used by RMP, were all highly significantly correlated in both habitats (Table 7), they were more highly correlated in the Estuarine habitat than in bay habitat. Although, each indicator was derived independently, and used different approaches, they all appear to provide similar measurements of the range of contamination in a sample.

Table 7. Correlations among the scores of three contamination indicators in the EMAP, RMP and BPTCP samples for each benthic habitat.
Shading = significant p.

	Bay, n=62		Estuarine, n=45	
	Spearman's r	p	Spearman's r	p
CA LRM : CSI	0.338	0.007	0.613	<.001
CA LRM : mERMq	0.527	<.001	0.762	<.001
CSI : mERMq	0.575	<.001	0.743	<.001

Toxicity indicators

In addition to the *Eohaustorius* bioassay, the bivalve larvae elutriate test was conducted at the RMP sites and included in the assessment of those samples. The amphipod and bivalve categories (1-4) agreed in only 22.7% of the RMP samples, but agreed in toxic (3,4) or not toxic (1,2) designations at 51.5% of the samples.

Benthic indicators

Analyses conducted during the development of the benthic indicators for the SQOs showed that the four benthic indices used in the bay habitat assessments were highly significantly correlated with expert opinion on disturbance categories, and that the indices assigned categories correctly with 71 - 89% accuracy (Ranasinghe *et al.* 2007a). Using all of the San Francisco Estuary data, most benthic indices were significantly correlated with each other in the bay habitat (Table 8). RIVPACS was not included as it is not a linear index. The IBI and RBI were not significantly correlated in either habitat.

The IBI and RBI were the only indices available for use in the estuarine habitat. The category scores for those two indices only agreed at 20% of the sites, and the impacted /not impacted designation only agreed at 33.3% of the sites.

Table 8. Correlations among benthic index scores from the EMAP and RMP/BPTCP samples, in the two habitats. Shading = p<0.05.

Bay	n	r_s
BRI : IBI	61	0.278
BRI : RBI	61	-0.597
RBI : IBI	62	-0.176
Estuarine		
RBI : IBI	45	0.034

Relationships between toxicity and chemistry indicators

Eohaustorius survival was not significantly correlated with CA LRM, CSI, or mERMq scores in the bay habitat, but was significantly correlated to all three chemistry indicators in the estuarine habitat (Table 9). CSI was most highly associated with toxicity (but was not significant) in the bay habitat, and CA LRM was most highly associated in the Estuarine habititat. Reasons for these differences are not clear. CA LRM scores above the 'impacted' threshold (0.5) were a reliable indicator of amphipod toxicity: 75.8% of the samples above the CA LRM threshold were toxic in the amphipod test.

The toxicity and chemistry LOE categories were not significantly correlated in either habitat (Table 10). The addition of the bivalve test in the RMP samples improved the correlations only slightly in the bay habitat, but was still not significant. It did not improve the correlations in the estuarine habitat.

Table 9. Correlations between *Eohaustorius* survival and contaminant indicator scores in the EMAP, RMP and BPTCP samples. Shading = p<0.05

	Bay, n=62		Estuarine, n=45	
	Spearman's r	p	Spearman's r	p
CA LRM	-0.119	0.36	-0.451	0.002
CSI	-0.217	0.09	-0.387	0.009
mERMq	-0.173	0.18	-0.348	0.019

Table 10. Correlations among the three LOE categories in the EMAP, RMP and BPTCP samples. Shading = p<0.05

	Bay, n=62		Estuarine, n=45	
	Spearman's r	p	Spearman's r	p
Benthic : Chem	0.349	0.006	-0.099	0.519
Tox : Chem	0.147	0.255	0.292	0.052
Ben : Tox	0.307	0.015	-0.308	0.04

Relationships between benthic and chemistry indicators
The CSI was significantly correlated with BRI, IBI, and RBI in the bay habitat, and with RBI in the estuarine habitat (Table 11). RIVPACS was not included in this analysis because the scores are non-linear. IBI and RBI were significantly correlated with CA LRM in the bay, but not in the estuarine habitat. RBI was significantly correlated with mERMq in the bay habitat. All three benthic indices evaluated were significantly correlated with sediment-type, percent fines and TOC, in the bay habitat. In the Estuarine habitat, RBI was significantly correlated with percent fines. Salinity was significantly correlated only with BRI in the bay habitat. The benthic and chemistry LOE categories were significantly correlated in the bay, but not in the estuarine habitat (Table 10).

Although the CSI and benthic index scores were well correlated, the CSI was not a very accurate predictor of benthic disturbance. Only 29.4% of samples with benthic disturbance had CSI scores above the 'moderate exposure' threshold of 2.33. This low association may be due to the fact that the CSI thresholds were derived from relationships between southern California benthos and sediment chemistry and did not include information from northern California.

That most of the benthic indices were associated with sediment-type illustrates why the benthic LOE categories are termed 'disturbance' rather than impact. The identification of possible causes of benthic disturbance, whether sediment contamination or other non-anthropogenic factors, will require additional data analyses and special studies as recommended in the Conclusions.

Table 11. Correlations between benthic index scores and contaminant indicator scores and non-anthropogenic factors in the EMAP, RMP, and BPTCP samples. Shading = $p<0.05$.

	Bay, n=62			Estuarine, n=45	
	BRI	**IBI**	**RBI**	**IBI**	**RBI**
CA LRM	0.21	0.256	-0.317	0.098	0.209
CSI	0.397	0.357	-0.274	-0.066	0.39
mERMq	0.205	0.219	-0.337	0.14	0.256
Salinity	-0.322	-0.069	0.096	0.128	0.091
% Fines	0.534	0.381	-0.654	0.009	0.302
TOC	0.469	0.324	-0.486	0.195	0.223

Relationships between benthic and toxicity indicators
The benthic LOE category was significantly correlated with the toxicity LOE category in both habitats (Table 10), which indicates that both LOEs reflect similar degrees of sediment impact. However, the Estuarine habitat relationship was inverse and opposite to what would be expected, possibly related to the fact that only two benthic indices have

been developed for that habitat, and they only agreed at 20% of the sites (see section *Relationships among the SQO indicators, indices, and LOEs - Benthic Indicators* above).

Stressor Identifications

An evaluation of the contaminants and non-anthropogenic factors that were associated with sediment toxicity and benthic disturbance was conducted using correlation analysis and comparison to ERL, ERM, and mERMq guidelines. These evaluations should not be interpreted as evidence of cause and effect. They were conducted to demonstrate preliminary steps that may focus more rigorous studies of the causes of observed sediment impacts.

Toxicity

Sediment toxicity was significantly correlated with specific contaminants at the RMP sites at Alameda (BB70) and Yerba Buena Is. (BC11) in the Central Bay (Table 12). None of the samples at BB15 or BC21 were toxic, so no stressor evaluations were conducted at those sites.

LPAHs were significantly correlated with *Eohaustorius* toxicity at Alameda, and were also above the ERLs at that site. Samples with LPAH concentrations above 586 ppb were always toxic. That concentration is comparable to the ERL guideline of 552 ppb, and to the concentration of 474 ppb similarly derived by Thompson *et al*. (1999).

DDTs were significantly correlated with toxicity at Yerba Buena Is., and were above the ERL. Zinc and Pb were also significantly correlated with toxicity at Yerba Buena Is; pp-DDE concentrations above 0.85 ppb were always toxic at that site, a concentration below the ERL of 2.2 ppb.

Mercury was above the ERM at the San Leandro Bay site. There were no significant correlations between sediment contamination and toxicity in the EMAP samples among the bay or estuarine habitat samples. Chlordanes were above the ERM (6 ppb) at 25% of the sites from scattered locations in both bay and estuarine habitats, and concentrations above 3.0 ppb were always toxic. Chlordanes above 0.3 were considered to be a toxicity threshold in previous studies by Thompson *et al.* (1999). Cu, Hg, and dieldrin were above ERMs at less than 10% of the sites.

Several contaminants were above guidelines and/or correlated with toxicity in all samples. However, mERMqs were above the threshold of 0.185 for toxicity in only 6 samples, which were all toxic. Only 9.5% of all toxic samples were above that threshold.

Table 12. Sediment contaminants that exceeded Effects Range guidelines in more than half of the toxic samples, and that were significantly correlated with E*ohaustorius* toxicity.

Method	Station (n toxic samples)								
	BA21 (5)	**BA41 (5)**	**BB15 (0)**	**BB70 (2)**	**SLB-6 (1)**	**BC11 (5)**	**BC21 (0)**	**BD41 (1)**	**EMAP (33)**
ERMs					Hg				
ERLs	Cu	Cu	na	Cu	Cu	Cu	na	DDTs	Cu
	Hg	Hg		Hg	Hg	Hg		Chlordanes	Hg
	DDTs	HPAHs		LPAH	Zn	DDTs			DDTs
	Chlordanes	DDTs		HPAH	Pb				Chlordanes
				DDTs					Dieldrin
				Dieldrin					

Table 12. Sediment contaminants that exceeded Effects Range guidelines in more than half of the toxic samples, and that were significantly correlated with E*ohaustorius* toxicity.

Method	Station (n toxic samples)								
	BA21 (5)	BA41 (5)	BB15 (0)	BB70 (2)	SLB-6 (1)	BC11 (5)	BC21 (0)	BD41 (1)	EMAP (33)
Correlations				LPAHs		Pb			
(p<0.05)						Zn			
						pp DDE			
						pp DDT			

Benthos

Benthic disturbance was significantly correlated with several trace organic contaminants at the RMP South Bay (BA21) and Redwood Creek (BA41) sites (Table 13). LPAHs, dieldrin, and PCBs were significantly correlated to benthic impacts at South Bay, and were also above the ERL guidelines. Concentrations of LPAHs above 794 ppb, and concentrations of dieldrin above 0.84 ppb were always associated with benthic disturbance. These concentrations are between the ERL and ERM guidelines.

HPAHs were significantly correlated, and above ERL guidelines at Redwood Creek. Concentrations above 2,354 ppb were always associated with benthic disturbance. That concentration is between the ERL and ERM guidelines. Sediment mixtures (mERMq) were also significantly correlated with disturbance at Redwood Creek.

Similar to the toxicity evaluations, Hg was above the ERM (0.71 ppm) value in the sample from San Leandro Bay. Similar results were reported by Melwani and Thompson (2007) based on analyses of five samples in San Leandro Bay, where Hg concentrations above 0.3 ppm were associated with benthic impacts.

The only significant correlation at San Bruno Shoal was sediment grain-size (% fines). Although most of the samples in San Pablo Bay (BD41) showed benthic disturbance, there was little association with specific contaminants. These results suggest that other factors such as resuspended sediments or unmeasured contaminants that were either not used in the SQO assessment (only 17 contaminants were evaluated) or not measured in the Estuary (e.g. emerging contaminants of concern) should be investigated in future assessments.

There were no significant correlations between sediment contaminants and benthic disturbance among the EMAP samples from either the bay or estuarine habitats. Chlordanes were above the ERM in 15% of the EMAP samples, and Cu, Hg and dieldrin were above the ERM in less than 3%. There was no apparent threshold for chlordanes effects on benthos. However, Melwani and Thompson (2007) reported chlordanes concentrations above 10.4 ppb were associated with benthic impacts in San Leandro Bay.

Table 13. Sediment contaminants that exceeded Effects Range guidelines in more than half of the samples with benthic disturbance, and that were significantly correlated with benthic disturbance.

Method	Station (n disturbed samples)								
	BA21 (2)	BA41 (5)	BB15 (2)	BB70 (1)	SLB-6 (1)	BC11 (0)	BC21 (0)	BD41 (5)	EMAP (17)
ERMs					Hg				
ERLs	Cu	Cu	Cu	Hg	Cu	na	na	Dieldrin	Cu
	Hg	Hg	Hg	DDTs	Hg				Hg
	Zn	HPAH	HPAH		Zn				DDTs
	HPAH	DDTs			Pb				Chlordanes
	LPAH	Dieldrin							Dieldrin
	DDTs								
	Dieldrin								
	Chlordanes								
	PCBs								
Correlations (at least one benthic index, $p<0.05$)	LPAHs	HPAHs	% Fines						
	Dieldrin	LPAHs							
	PCBs	mERMq							

CONCLUSIONS

The RMP sites had incidence of impacts ranging from 80% at Redwood Creek (BA41) to none in Horseshoe Bay (BC21). All sites evaluated (except BC21) showed variation in sediment condition over time. These variations probably reflect changes in sediment contamination, toxicity, and benthic communities related to seasonal and annual changes in run-off, salinity, and contaminant loadings: but there were no obvious patterns related to those factors. The three LOEs usually appear to provide a adequate, independent assessments about possible sediment impacts. Overall, the results of the assessments were generally consistent with previous RMP sediment evaluations that have been reported for over the history of the program.

The statewide assessment that employed the EMAP-2000 study results indicated a considerably higher incidence of sediment impact (i.e. higher SQO scores), and category score in each of the LOEs. Difference in sample design between the EMAP and RMP studies, the use of a single toxicity test in the EMAP-2000 assessment, and the fact that the EMAP survey followed five years of above normal runoff appears to explain some of the differences. The differences between the EMAP and RMP assessments emphasize the importance of considering temporal and seasonal trends, and sampling locations when interpreting sediment assessments. Since 2002, the RMP moved to the Generalized Random Tessellation Stratified (GRTS) sampling design (the same as employed by the EMAP-2000 study) and assessment of RMP samples in the future will help improve our understanding of spatial and temporal variability in sediment condition related to natural and anthropogenic factors.

The SQO indicators and assessment framework provide a technically sound and consistent basis for assessing sediment condition in San Francisco Estuary. The SQO assessment procedures have been extensively reviewed and many of them have been published in the scientific literature. The evaluations of relationships among the indicators, indices, and LOEs shown in this report demonstrate that most of the component measurements used in the SQOs provide reasonable assessments of sediment condition, and are generally consistent with similar information that the RMP has used for many years (e.g. ERL-M thresholds, incidence of toxicity, benthic disturbance, etc.). However, a few components were identified as needing additional development and testing (see recommendations below).

The relationships between the toxicity and chemistry indicators were generally weak (i.e. no significant correlation). Amphipod survival was not significantly correlated with the chemistry indicator scores in the bay habitat, and the toxicity and chemistry LOE category scores were not significantly correlated. The reasons for the general lack of association between toxicity and contamination are not clear. It may reflect the limited list of contaminants included in the chemistry assessment. Other pesticides such as organophosphates and pyrethroids as well as PBDEs, emerging contaminants, and volatile compounds were not included and may potentially contribute to impacts. However, it is emphasized that this lack of association is why the SQO framework uses multiple lines of evidence: there is insufficient understanding of cause and effect among the LOEs to rely on any single one.

The benthic indices used in SQO assessments (excluding RIVPACS) were mostly significantly correlated with each other, and with the contaminant indices in the bay habitats, but not in the estuarine habitats. However, they were also significantly correlated with sediment-type, which may confound efforts to identify possible contaminant stressors of benthic disturbance. The benthic indices used in the Estuarine habitats need to be critically evaluated and validated for use in the SQOs (see recommendations below).

The brief stressor identification evaluations examined individual contaminants that may be contributing to the observed SQO sediment impacts. However, all sediments studied included various mixtures of contaminants, and multiple contaminants were identified by all stressor evaluation methods. Therefore, sediment impacts identified by SQO assessments should be interpreted as probably resulting from sediment mixture effects. The goal of stressor identification evaluations is to narrow down the list of possible contaminants in these mixtures that are correlated with the observed sediment impacts, so that management actions can be efficiently focused on reducing the sources and/or pathways of contaminant loads to the Estuary that are most likely responsible for the observed impacts.

Sediment toxicity and benthic disturbance were associated with slightly different contaminants at the RMP sites in the South Bay than in the Central Bay. High and low molecular weight PAHs, dieldrin, and PCBs were significantly correlated with benthic disturbance at South Bay and Redwood Creek, and LPAHs and DDT were associated with sediment toxicity at Alameda and Yerba Buena Is. Mercury concentrations at the San Leandro Bay site were above the ERM. Benthic disturbance in San Pablo Bay were poorly associated with contamination, suggesting that other contaminants or non-anthropogenic factors may have affected benthic disturbances at that site. There were no

significant correlations between benthic disturbance or toxicity and contaminant concentrations, in either habitat, among the EMAP samples. Chlordanes were most frequently above ERL or ERM guidelines at the EMAP sites.

Sediment grain-size was significantly correlated with benthic disturbance at San Bruno Shoal, and most of the benthic indices were significantly correlated with sediment-type, suggesting that sediment-type may have influenced the benthic results. Recent studies of factors that influence the benthos in the Estuary showed both contaminants and non-anthropogenic factors (such as grain-size, salinity, and TOC) were associated with benthic impacts in some areas of the Estuary (Melwani and Thompson, 2008). Non-anthropogenic factors must be included in stressor identification evaluations to appropriately identify influences on benthos.

Apparent effects thresholds for the contaminants associated with impacts in the stressor evaluations were consistent with those observed in previous studies in the Estuary, and were usually between the ERL and ERM guidelines. The contaminants and concentrations identified may provide useful hypotheses for further studies on possible causes of sediment impacts. Stressor identification evaluations conducted in the future should include more rigorous numerical analyses of associations (multivariate analyses, covariance, etc.). Stressor identifications may also include comparisons to known effects thresholds. Unfortunately, there are very few LC50 values in the literature for estuarine organisms used in sediment toxicity tests, but such information would be extremely useful in stressor identification evaluations. Equilibrium partitioning values may be calculated for some trace organic compounds as possible effects thresholds for comparison to ambient concentrations. However, definitive determination of cause and effect will require laboratory experiments followed by field verification (see recommendation below).

Next steps

The use of the SQO methodology will provide a more consistent and rigorous assessment of sediment condition in the future. However, the analyses and results included in this report have shown several areas where additional information or methods are needed.

1. The CSI indicator was developed using empirical relationships between contamination and benthos in southern California. The current CSI should be validated for San Francisco Estuary, or a revised version of the CSI should be developed using San Francisco Estuary data.

2. The SQO methods recommend the use of two toxicity tests. The RMP will be sampling for SQO measures in 2008 and has decided to employ the intact sediment cores for the sub-lethal bivalve development test. Further study is warranted to compare the use of intact sediment cores with resettled homogenate sediment samples in order to further develop the sediment water interface methodology.

3. The four benthic indices used in the bay (polyhaline) habitat have been extensively tested and evaluated and shown to be highly effective. However, similar testing and evaluations have not been conducted for the estuarine (mesohaline) habitat. Evaluations of the two existing estuarine benthic indices (IBI, RBI) should be conducted, similar to the assessment implemented for the bay habitat (Weisberg *et al*., 2008), or new indices

need to be developed. In addition, no benthic indices currently exist for use in the oligohaline (Suisun Bay, lower major river reaches), or brackish water (Delta) habitats. The SQO Phase 2 program is scheduled to address the freshwater Delta habitat.

4. Expand the list of contaminants included in the chemistry indicators. It will be extremely difficult to create chemical indicators that include all of the possible contaminants. But future efforts should certainly attempt to identify those that have the highest potential for biological effects and incorporate them into revised versions. This is being done to a limited extent as the SQO program expands into the Delta. Pyretheroids and other pesticides will be measured and considered for inclusion in the chemistry exposure LOE.

5. The RMP should continue to develop stressor identification methods to determine cause and effect for observed toxicity and benthic disturbance. The RMP's Exposure and Effects Work Group (EEWG) has included some studies as part of their recently approved Five-year work plan. These studies are focused on sediment toxicity, as that biological indicator was shown in this report to be most frequently impacted. The planned studies include gradient studies and TIEs, and evaluation of associated benthic disturbance. However, experimental studies where only one variable at a time are manipulated, is the only way to conclusively show cause and effect. The use of individual contaminants mixtures in experimental systems, such as mesocosms, where non-anthropogenic, environmental factors (such as grain-size, TOC, or salinity) can also be manipulated will be time consuming and expensive, but there is no other way to definitively establish cause and effect that can properly focus management and remedial actions.

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Appendix A - Draft Water Quality Control Plan for Enclosed Bays and Estuaries - -Part 1 Sediment Quality
Appendix B - Environmental Checklist
Appendix C - Example Problem

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APPENDIX 1. DATA USED
INCLUDING INDICATORS, INDICES, SQO CATEGORIES AND SCORES

Table 1.a EMAP- 2000 SQO Assessment: Physical Characteristics & Benthos Assessment Results

Station	Date	Salinity	% Fines	% TOC	Habitat	BRI Score	IBI Score	RBI Score	RIV Score	BRI Cat	IBI Cat	RBI Cat	RIV Cat	Benthic LOE
CA000001	7/31/2000	28.8	98.1	1.5	bay, port	36.8	0	0.12	0.46	3	1	4	2	3
CA00-0002	7/26/2000	28.6	96.4	1.2	bay, port	40.3	0	0.06	0.23	3	1	4	3	3
CA00-0003	7/26/2000	28.8	55.1	0.7	bay, port	17.9	0	0.08	0.53	1	1	4	2	2
CA00-0004	8/2/2000	28.0	84.9	2.1	estuary		0	0.36			1	1		1
CA00-0005	7/27/2000	28.6	95.1	1.3	bay	32.3	0	0.13	0.53	2	1	4	2	2
CA00-0006	7/27/2000	28.1	90.2	1.7	bay	27.5	0	0.15	0.49	2	1	4	2	2
CA00-0007	7/28/2000	27.4	95.5	1.5	bay	36.9	1	0.08	0.39	3	1	4	2	3
CA00-0009	8/17/2000	27.6	89.2	2.0	bay	53.4	1	0.15	0.43	3	1	4	2	3
CA00-0010	7/29/2000	27.6	94.1	1.4	estuary		0	0.14			1	3		2
CA00-0011	7/29/2000	27.6	96.3	1.6	estuary		1	0.21			1	3		2
CA00-0012	8/17/2000	27.5	65.4	1.1	bay	61.3	0	0.15	0.39	3	1	4	2	3
CA00-0013	7/29/2000	28.2	97.4	1.6	estuary, port		0	0.17			1	3		2
CA00-0014	8/1/2000	17.5	95.9	1.6	estuary		1	0.11			1	4		3
CA00-0015	8/17/2000	21.9	92.5	1.7	estuary		1	0.13			1	4		3
CA00-0017	7/21/2000	28.4	97.1	1.5	bay, marina	53.5	3	0.10	0.43	3	3	4	2	3
CA00-0021	7/14/2000	11.2	68.1	1.0	estuary		0	0.13			1	4		3
CA00-0022	7/15/2000	15.4	95.0	1.8	estuary		1	0.20			1	3		2
CA00-0023	7/18/2000	20.5	98.2	1.3	estuary		1	0.04			1	4		3
CA00-0026	7/19/2000	20.1	93.8	1.2	estuary		1	0.17			1	3		2
CA00-0027	7/19/2000	20.1	96.6	1.4	estuary		0	0.19			1	3		2
CA00-0028	8/16/2000	21.0	93.5	1.4	estuary		1	0.31			1	2		2
CA00-0029	7/16/2000	24.7	34.8	0.6	estuary		2	0.11			2	4		3
CA00-0030	3/16/2000	21.6	95.4	1.4	estuary		0	0.61			1	1		1
CA00-0031	7/19/2000	25.0	96.4	1.5	estuary		0	0.18			1	3		2
CA00-0032	7/20/2000	28.5	92.3	1.5	bay	32.8	0	0.13	0.51	2	1	4	2	2
CA00-0033	7/17/2000	27.6	65.9	1.5	bay	32.3	0	0.11	0.51	2	1	4	2	2

CA00-0034	7/21/2000	27.4	83.6	1.2	bay	16.2	1	0.20	0.55	1	1	3	2	2
CA00-0035	7/23/2000	29.2	80.3	1.3	bay	19.3	0	0.29	0.73	1	1	2	1	1
CA00-0036	7/26/2000	28.6	89.1	1.5	bay, port	15.3	0	0.14	0.54	1	1	4	2	2
CA00-0037	7/20/2000	28.6	98.5	1.3	bay	32.7	1	0.08	0.55	2	1	4	2	2
CA00-0039	8/4/2000	23.1	55.0	1.7	estuary		1	0.10			1	4		3
CA00-0041	8/4/2000	22.0	99.6	1.7	estuary		0	0.13			1	4		3
CA00-0043	7/27/2000	15.4	95.1	2.0	estuary		1	0.18			1	3		2
CA00-0044	8/3/2000	25.5	95.9	1.3	esuary		3	1.00			3	1		2
CA00-0045	7/28/2000	28.0	49.6	2.3	bay, port	45.0	0	0.26	0.63	3	1	3	2	3
CA00-0046	7/24/2000	25.9	100.0	2.0	estuary		5	0.52			4	1		3
CA00-0047	8/3/2000	21.0	97.6	1.5	estuary		0	0.67			1	1		1
CA00-0048	8/3/2000	21.3	98.6	1.5	estuary		1	0.21			1	3		2
CA00-0049	7/25/2000	28.7	95.1	1.7	bay	34.7	0	0.18	0.60	3	1	4	2	3
CA00-0050	7/25/2000	25.5	96.6	0.9	bay	52.9	0	0.15	0.34	3	1	4	2	3

Table 1.b EMAP- 2000 SQO Assessment: Toxicity Data and Assessment Results

Station	Date	Eo % surv.	Eo Cat	Biv % norm.	Biv Cat	Tox. LOE	Pmax
CA00-0001	7/31/2000	49.5	4			4	0.50
CA00-0002	7/26/2000	86.9	2			2	0.54
CA00-0003	7/26/2000	71.7	3			3	0.45
CA00-0004	8/2/2000	66.0	3			3	0.66
CA00-0005	7/27/2000	69.7	3			3	0.52
CA00-0006	7/27/2000	80.8	3			3	0.47
CA00-0007	7/28/2000	38.4	4			4	0.54
CA00-0009	8/17/2000	33.3	4			4	0.50
CA00-0010	7/29/2000	18.2	4			4	0.45
CA00-0011	7/29/2000	49.5	4			4	0.48
CA00-0012	8/17/2000	58.3	4			4	0.43
CA00-0013	7/29/2000	58.6	3			3	0.54
CA00-0014	8/1/2000	90.6	2			2	0.53
CA00-0015	8/17/2000	55.2	4			4	0.56
CA00-0017	7/21/2000	60.2	3			3	0.73
CA00-0021	7/14/2000	82.3	2			2	0.46
CA00-0022	7/15/2000	69.8	3			3	0.50
CA00-0023	7/18/2000	85.7	2			2	0.49
CA00-0026	7/19/2000	77.6	3			3	0.56
CA00-0027	7/19/2000	64.3	3			3	0.56
CA00-0028	8/16/2000	53.1	4			4	0.50
CA00-0029	7/16/2000	91.7	2			2	0.40
CA00-0030	3/16/2000	42.7	4			4	0.56
CA00-0031	7/19/2000	77.6	3			3	0.54
CA00-0032	7/20/2000	71.4	3			3	0.51
CA00-0033	7/17/2000	62.5	3			3	0.44
CA00-0034	7/21/2000	82.7	2			2	0.49
CA00-0035	7/23/2000	50.0	4			4	0.43
CA00-0036	7/26/2000	72.7	3			3	0.53
CA00-0037	7/20/2000	59.2	3			3	0.53
CA00-0039	8/4/2000	69.4	2			2	0.71
CA00-0041	8/4/2000	52.1	4			4	0.46
CA00-0043	7/27/2000	65.7	3			3	0.43
CA00-0044	8/3/2000	54.2	4			4	0.43
CA00-0045	7/28/2000	69.4	3			3	0.71
CA00-0046	7/24/2000	40.1	4			4	0.53
CA00-0047	8/3/2000	55.2	4			4	0.47
CA00-0048	8/3/2000	44.8	4			4	0.46
CA00-0049	7/25/2000	51.5	4			4	0.43
CA00-0050	7/25/2000	68.7	3			3	0.25

Table 1.c EMAP- 2000 SQO Assessment: Chemistry Data and Assessment Results

Station	Date	CALRM Cat	CSI	CSI Cat	Chem. LOE	SQO Score	mERMq
CA00-0001	7/31/2000	3	1.92	2	3	4	0.124
CA00-0002	7/26/2000	3	1.51	1	2	3	0.121
CA00-0003	7/26/2000	2	1.37	1	2	3	0.081
CA00-0004	8/2/2000	2	1.99	2	3	2	0.201
CA00-0005	7/27/2000	3	1.76	2	3	3	0.134
CA00-0006	7/27/2000	2	2.54	3	2	3	0.140
CA00-0007	7/28/2000	3	2.44	3	3	4	0.112
CA00-0009	8/17/2000	3	1.56	1	3	4	0.094
CA00-0010	7/29/2000	2	1.15	1	2	3	0.064
CA00-0011	7/29/2000	2	1.77	2	2	3	0.123
CA00-0012	8/17/2000	2	1.14	1	2	4	0.083
CA00-0013	7/29/2000	3	2.62	3	3	3	0.109
CA00-0014	8/1/2000	3	1.93	2	3	4	0.130
CA00-0015	8/17/2000	3	2.16	2	3	4	0.193
CA00-0017	7/21/2000	4	2.23	2	4	4	0.224
CA00-0021	7/14/2000	2	1.89	2	2	3	0.086
CA00-0022	7/15/2000	3	2.72	3	3	3	0.117
CA00-0023	7/18/2000	2	1.60	1	2	3	0.099
CA00-0026	7/19/2000	3	1.85	2	3	3	0.118
CA00-0027	7/19/2000	3	2.48	2	3	3	0.113
CA00-0028	8/16/2000	3	2.07	2	3	3	0.097
CA00-0029	7/16/2000	2	1.00	1	2	3	0.052
CA00-0030	3/16/2000	3	2.54	2	3	3	0.110
CA00-0031	7/19/2000	3	2.80	3	3	3	0.146
CA00-0032	7/20/2000	3	2.53	3	3	3	0.110
CA00-0033	7/17/2000	2	2.23	2	2	3	0.114
CA00-0034	7/21/2000	2	2.33	2	2	2	0.113
CA00-0035	7/23/2000	2	1.21	1	2	3	0.088
CA00-0036	7/26/2000	3	1.58	1	3	3	0.129
CA00-0037	7/20/2000	3	2.35	3	3	3	0.110
CA00-0039	8/4/2000	4	1.51	1	2	3	0.051
CA00-0041	8/4/2000	2	1.94	2	2	4	0.077
CA00-0043	7/27/2000	2	2.25	2	2	3	0.066
CA00-0044	8/3/2000	2	2.42	3	2	3	0.091
CA00-0045	7/28/2000	4	3.62	4	4	5	0.197
CA00-0046	7/24/2000	3	2.10	2	3	4	0.109
CA00-0047	8/3/2000	2	1.76	2	2	3	0.079
CA00-0048	8/3/2000	2	1.87	2	2	3	0.076
CA00-0049	7/25/2000	2	2.31	2	2	4	0.077
CA00-0050	7/25/2000	1	1.70	2	1	3	0.043

Table 2.a RMP, BPTCP SQO Assessment: Physical Characteristics & Benthos Assessment Results

Station	Date	Salinity	% Fines	% TOC	Habitat	BRI Score	IBI Score	RBI Score	RIV Score	BRI Cat	IBI Cat	RBI Cat	RIV Cat	Benthic LOE
SLB-6	4/17/1997	24.0	93.4	1.6	estuary		5	0.91			4	1		3
BB70	2/15/1994	27.6	82.0	1.1	bay	22.3	0	0.22	1.14	1	1	3	1	1
BB70	2/21/1995	19.6	76.0	1.0	bay	16.7	0	0.38	0.97	1	1	2	1	1
BB70	8/28/1995	28.3	97.0	2.2	bay	24.1	1	0.27	1.32	2	1	3	1	2
BB70	2/21/1996	18.7	80.0	1.0	bay	24.3	1	0.20	0.70	2	1	3	1	2
BB70	8/1/1996	29.8	85.0	1.2	bay	35.1	1	0.54	1.28	3	1	1	1	1
BB70	2/3/1997	9.7	90.0	1.2	bay	33.5	1	0.26	0.57	3	1	3	2	3
BB70	8/12/1997	30.6	64.0	1.1	bay	32.0	0	0.34	1.06	2	1	2	1	2
BB70	2/10/1998	12.9	74.0	1.1	bay	30.5	0	0.22	1.23	2	1	3	1	2
BB70	8/3/1998	26.8	70.0	0.9	bay	42.4	0	0.32	1.06	3	1	2	1	2
BB70	7/24/2000	29.1	70.0	1.1	bay	35.3	1	0.31	1.09	3	1	2	1	2
BC11	2/14/1994	27.9	43.0	0.8	bay	15.0	0	0.28	1.05	1	1	3	1	1
BC11	2/20/1995	22.2	67.0	1.2	bay	11.8	0	0.38	1.19	1	1	2	1	1
BC11	8/28/1995	28.9	92.0	1.7	bay	23.3	1	0.31	0.95	2	1	2	1	2
BC11	2/20/1996	23.4	78.0	1.1	bay	21.6	0	0.19	0.70	1	1	4	1	1
BC11	8/1/1996	31.1	61.0	1.0	bay	21.0	0	0.39	0.95	1	1	2	1	1
BC11	2/3/1997	.	70.0	1.0	bay	28.3	0	0.37	0.69	2	1	2	1	2
BC11	8/11/1997	29.8	38.0	0.9	bay	18.7	0	0.48	0.93	1	1	1	1	1
BC11	2/9/1998	14.0	74.0	1.2	bay	23.4	0	0.21	0.79	2	1	3	1	2
BC11	8/3/1998	25.2	78.0	1.5	bay	34.9	1	0.20	0.84	3	1	3	1	2
BC11	7/24/2000	29.2	77.0	1.0	bay	16.6	0	0.36	0.93	1	1	2	1	1
BC21	2/14/1994	29.9	65.0	1.1	bay	5.6	0	0.66	0.77	1	1	1	1	1
BC21	2/20/1995	20.1	66.0	1.0	bay	1.5	0	0.74	0.55	1	1	1	2	1
BC21	8/28/1995	30.8	31.0	0.6	bay	5.5	0	0.92	0.91	1	1	1	1	1
BC21	2/20/1996	25.5	30.0	0.8	bay	5.8	0	0.66	0.77	1	1	1	1	1
BC21	8/2/1996	31.4	41.0	0.7	bay	2.7	1	1.00	0.75	1	1	1	1	1
BC21	2/3/1997	10.9	48.0	0.7	bay	13.3	0	0.61	0.37	1	1	1	2	1
BC21	8/11/1997	31.2	34.0	0.7	bay	2.9	0	0.97	1.11	1	1	1	1	1
BC21	2/9/1998	15.9	43.0	0.7	bay	9.5	0	0.68	0.87	1	1	1	1	1
BC21	8/3/1998	31.8	26.0	0.5	bay	6.6	0	0.70	1.16	1	1	1	1	1
BC21	7/24/2000	30.7	33.0	0.7	bay	3.0	0	0.29	0.82	1	1	2	1	1
BA41	2/15/1994	27.3	88.0	0.8	bay	37.8	1	0.09	0.58	3	1	4	2	3
BA41	2/21/1995	16.3	67.0	1.6	bay	37.7	1	0.33	0.67	3	1	2	2	2
BA41	8/29/1995	24.4	80.0	1.1	bay	49.4	0	0.22	0.58	3	1	3	2	3
BA41	2/21/1996	17.4	88.0	1.2	bay	57.7	1	0.18	0.53	3	1	4	2	3
BA41	8/1/1996	26.4	93.0	1.2	bay	53.3	1	0.18	0.63	3	1	4	2	3
BA41	2/4/1997	8.7	97.0	1.2	estuary		0	1.00			1	1		1
BA41	8/12/1997	30.2	76.0	1.2	estuary		0	0.25			1	2		2
BA41	2/10/1998	13.7	97.0	1.3	bay	41.6	0	0.34	0.68	3	1	2	2	2
BA41	8/4/1998	23.2	72.0	1.3	bay	53.8	0	0.17	0.72	3	1	4	1	2
BA41	36732	23.4	69.0	1.2	bay		1	1.00		3	1	4	1	3
BB15	34751	17.0	82.0	1.1	estuary		1	0.22			1	3		2
BB15	34940	25.8	66.0	0.9	bay	54.0	0	0.19	0.99	3	1	4	1	2

Station	Date	Salinity	% Fines	% TOC	Habitat	BRI Score	IBI Score	RBI Score	RIV Score	BRI Cat	IBI Cat	RBI Cat	RIV Cat	Benthic LOE
BB15	35116	17.8	89.0	1.2	bay	53.9	1	0.17	0.87	3	1	4	1	2
BB15	35278	27.5	54.0	0.8	bay	59.9	0	0.24	0.86	3	1	3	1	2
BB15	35465	15.5	58.0	0.8	estuary		1	0.54			1	1		1
BB15	35654	30.4	48.0	1.1	estuary		0	0.30			1	2		2
BB15	35836	15.5	92.0	1.3	bay	45.1	0	0.15	1.08	3	1	4	1	2
BB15	36011	24.3	96.0	1.5	bay	62.7	0	0.25	0.65	3	1	3	2	3
BB15	36732	28.8	99.0	1.5	bay	53.8	1	0.05	0.42	3	1	4	2	3
BA21	34381	25.2	81.0	0.8	estuary		2	0.10			2	4		3
BA21	34751	14.4	97.0	1.0	estuary		0	0.51			1	1		1
BA21	34940	23.4	98.0	1.3	estuary		0	0.15			1	3		2
BA21	35116	14.9	99.0	1.5	estuary		0	0.14			1	3		2
BA21	35278	22.4	97.0	1.4	estuary		0	0.23			1	2		2
BA21	35465	6.7	97.0	1.4	estuary		0	0.89			1	1		1
BA21	35654	28.4	91.0	1.4	estuary		0	0.29			1	2		2
BA21	35836	10.0	97.0	1.4	estuary		0	0.17			1	3		3
BA21	36011	20.6	97.0	1.4	estuary		1	0.26			1	2		2
BA21	36732	25.3	96.0	1.4	estuary		1	0.49			1	1		1
BD41	34936	16.1	20.0	0.4	estuary		0	0.05			1	4		3
BD41	35111	10.0	18.0	0.2	estuary		0	0.08			1	4		3
BD41	35282	23.9	13.0	0.3	estuary		0	0.00			1	4		3
BD41	35650	24.5	8.0	0.1	estuary		0	0.47			1	1		1
BD41	35832	1.0	33.0	0.8	estuary		0	0.15			1	3		2
BD41	36007	23.0	15.0	0.3	estuary		0	0.12			1	4		3
BD41	36728	22.2	20.0	0.5	estuary		1	0.11			1	4		3

Table 2.b RMP, BPTCP SQO Assessment: Toxicity Data and Assessment Results

Station	Date	Eo % surv.	Eo Cat	Biv % norm.	Biv Cat	Tox. LOE	Pmax
SLB-6	4/17/1997	65.0	3			3	0.67
BB70	2/15/1994	54.6	4	67.35	3.00	4	0.43
BB70	2/21/1995	56.2	4	102.11	1.00	3	0.46
BB70	8/28/1995	86.2	2	85.00	1.00	2	0.44
BB70	2/21/1996	82.7	2	84.42	1.00	2	0.50
BB70	8/1/1996	75.5	3	101.23	1.00	2	0.46
BB70	2/3/1997	80.6	3	84.04	1.00	2	0.49
BB70	8/12/1997	75.8	3	98.89	1.00	2	0.47
BB70	2/10/1998	77.3	3	85.71	1.00	2	0.47
BB70	8/3/1998	84.7	2	93.14	1.00	2	0.49
BB70	7/24/2000	68.7	3	98.13	1.00	2	0.48
BC11	2/14/1994	85.6	1	94.90	1.00	1	0.32
BC11	2/20/1995	92.7	1	97.89	1.00	1	0.37
BC11	8/28/1995	54.1	4	77.00	2.00	3	0.45
BC11	2/20/1996	65.3	3	98.70	1.00	2	0.48
BC11	8/1/1996	57.1	4	112.35	1.00	3	0.41
BC11	2/3/1997	77.6	3	92.55	1.00	2	0.41
BC11	8/11/1997	55.6	4	90.56	1.00	3	0.45
BC11	2/9/1998	63.9	3	98.81	1.00	2	0.42
BC11	8/3/1998	35.7	4	0.00	4.00	4	0.45
BC11	7/24/2000	31.3	4	87.85	1.00	3	0.44
BC21	2/14/1994	85.6	2	91.84	1.00	2	0.67
BC21	2/20/1995	89.6	2	94.74	1.00	2	0.41
BC21	8/28/1995	89.2	2	98.20	1.00	2	0.30
BC21	2/20/1996	75.5	3	94.81	1.00	2	0.62
BC21	8/2/1996	87.8	2	107.41	1.00	2	0.53
BC21	2/3/1997	81.6	2	88.30	1.00	2	0.40
BC21	8/11/1997	91.9	1	99.67	1.00	1	0.34
BC21	2/9/1998	91.8	2	89.29	1.00	2	0.61
BC21	8/3/1998	94.9	1	100.00	1.00	1	0.40
BC21	7/24/2000	92.9	1	88.79	1.00	1	0.44
BA41	2/15/1994	64.9	3	94.90	1.00	2	0.47
BA41	2/21/1995	78.1	3	98.95	1.00	2	0.45
BA41	8/29/1995	63.1	3	93.80	1.00	2	0.47
BA41	2/21/1996	43.9	4	106.49	1.00	3	0.53
BA41	8/1/1996	77.6	3	101.23	1.00	2	0.49
BA41	2/4/1997	21.4	4	92.55	1.00	3	0.48
BA41	8/12/1997	56.6	4	100.00	1.00	3	0.50
BA41	2/10/1998	71.1	3	84.52	1.00	2	0.55
BA41	8/4/1998	57.1	4	96.08	1.00	3	0.46
BA41	36732	56.5	4.00	87.85	1.00	3	0.39
BB15	34751	80.2	3.00	94.74	1.00	2	0.43
BB15	34940	83.2	2.00	98.10	1.00	2	0.40
BB15	35116	83.7	2.00	80.52	1.00	2	0.43

Station	Date	Eo % surv.	Eo Cat	Biv % norm.	Biv Cat	Tox. LOE	Pmax
BB15	35278	89.8	2.00	104.94	1.00	2	0.40
BB15	35465	82.7	2.00	85.11	1.00	2	0.41
BB15	35654	89.9	2.00	103.33	1.00	2	0.39
BB15	35836	73.2	3.00	89.29	1.00	2	0.51
BB15	36011	84.7	2.00	88.24	1.00	2	0.52
BB15	36732	67.0	3.00	92.52	1.00	2	0.50
BA21	34381	57.7	4.00	100.00	1.00	3	0.47
BA21	34751	79.2	3.00	96.84	1.00	2	0.49
BA21	34940	91.2	1.00	94.80	1.00	1	0.46
BA21	35116	60.2	3.00	105.19	1.00	2	0.56
BA21	35278	85.7	2.00	3.70	4.00	3	0.50
BA21	35465	56.1	4.00	91.49	1.00	3	0.50
BA21	35654	90.9	1.00	96.67	1.00	1	0.50
BA21	35836	62.9	3.00	88.10	1.00	2	0.61
BA21	36011	44.9	4.00	71.57	3.00	4	0.53
BA21	36732	56.5	4.00	0.00	4.00	4	0.51
BD41	34936	96.2	1.00	99.00	1.00	1	0.35
BD41	35111	96.9	1.00	105.19	1.00	1	0.39
BD41	35282	100.0	1.00	109.88	1.00	1	0.38
BD41	35650	94.9	1.00	100.00	1.00	1	0.33
BD41	35832	100.0	1.00	39.29	4.00	3	0.43
BD41	36007	100.0	1.00	99.02	1.00	1	0.38
BD41	36728	94.9	1.00	92.52	1.00	1	0.39

Table 2.c RMP, BPTCP SQO Assessment: Chemistry Data and Assessment Results

Station	Date	CALRM Cat	CSI	CSI Cat	Chem. LOE	SQO Score	mERMq
SLB-6	4/17/1997	4	2.81	3	4	5	0.228
BB70	2/15/1994	2	2.16	2	2	3	0.162
BB70	2/21/1995	2	2.53	3	3	2	0.139
BB70	8/28/1995	2	2.46	3	3	3	0.104
BB70	2/21/1996	3	2.08	2	2	2	0.091
BB70	8/1/1996	2	2.24	2	2	1	0.097
BB70	2/3/1997	2	2.12	2	2	3	0.082
BB70	8/12/1997	2	2.16	2	2	2	0.124
BB70	2/10/1998	2	2.01	2	2	2	0.096
BB70	8/3/1998	2	2.65	3	3	3	0.126
BB70	7/24/2000	2	2.68	3	3	3	0.146
BC11	2/14/1994	1	2.00	2	2	1	0.082
BC11	2/20/1995	2	1.66	1	2	1	0.069
BC11	8/28/1995	2	2.09	2	2	3	0.082
BC11	2/20/1996	2	2.30	2	2	1	0.093
BC11	8/1/1996	2	1.27	1	2	2	0.075
BC11	2/3/1997	2	1.49	1	2	2	0.072
BC11	8/11/1997	2	1.84	2	2	2	0.093
BC11	2/9/1998	2	2.06	2	2	2	0.083
BC11	8/3/1998	2	2.37	3	3	3	0.142
BC11	7/24/2000	2	1.79	2	2	2	0.069
BC21	2/14/1994	4	2.05	2	3	2	0.159
BC21	2/20/1995	2	1.90	2	2	1	0.087
BC21	8/28/1995	1	1.12	1	1	1	0.054
BC21	2/20/1996	3	1.11	1	2	1	0.066
BC21	8/2/1996	3	1.73	2	3	2	0.094
BC21	2/3/1997	2	1.85	2	2	1	0.128
BC21	8/11/1997	2	1.36	1	2	1	0.056
BC21	2/9/1998	3	1.69	1	2	1	0.087
BC21	8/3/1998	2	1.69	2	2	1	0.079
BC21	7/24/2000	2	2.01	2	2	1	0.107
BA41	2/15/1994	2	2.66	3	3	4	0.158
BA41	2/21/1995	2	2.32	2	2	2	0.099
BA41	8/29/1995	2	2.47	3	3	4	0.101
BA41	2/21/1996	3	2.34	3	3	4	0.113
BA41	8/1/1996	2	2.23	2	2	3	0.114
BA41	2/4/1997	2	2.10	2	2	2	0.089
BA41	8/12/1997	2	2.83	3	3	3	0.102
BA41	2/10/1998	3	2.37	3	3	3	0.095
BA41	8/4/1998	2	2.24	2	2	3	0.102
BA41	36732	2	2.06	2	2	4	0.080
BB15	34751	2	2.30	2	2	2	0.095
BB15	34940	2	2.27	2	2	2	0.085
BB15	35116	2	1.91	2	2	2	0.089

Station	Date	CALRM Cat	CSI	CSI Cat	Chem. LOE	SQO Score	mERMq
BB15	35278	2	1.49	1	2	2	0.084
BB15	35465	2	1.70	2	2	1	0.075
BB15	35654	2	1.56	1	2	2	0.076
BB15	35836	3	2.02	2	3	3	0.081
BB15	36011	3	2.41	3	3	4	0.093
BB15	36732	3	3.05	4	3	4	0.094
BA21	34381	2	2.81	3	3	4	0.185
BA21	34751	2	2.45	3	3	2	0.103
BA21	34940	2	2.57	3	3	1	0.107
BA21	35116	3	3.06	4	4	3	0.144
BA21	35278	3	2.72	3	3	3	0.117
BA21	35465	3	2.69	3	3	2	0.108
BA21	35654	3	2.52	3	3	1	0.111
BA21	35836	3	2.65	3	3	4	0.106
BA21	36011	3	2.15	2	3	3	0.097
BA21	36732	3	2.38	3	3	3	0.082
BD41	34936	2	1.18	1	2	2	0.035
BD41	35111	2	1.00	1	2	2	0.038
BD41	35282	2	1.00	1	2	2	0.033
BD41	35650	1	1.06	1	1	1	0.039
BD41	35832	2	1.73	2	2	3	0.046
BD41	36007	2	1.05	1	2	2	0.038
BD41	36728	2	1.27	1	2	2	0.032