A Concept and Demonstration of A Water Contamination Index For The San Francisco Estuary

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A Report to

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Surface Water Ambient Monitoring Program

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Executive Summary

This report presents a concept and demonstration for a Water Contamination Index (WCI) for San Francisco Estuary. The purpose of this index is to assess impacts of exposure to water contamination on aquatic life in San Francisco Estuary. It is intended that the WCI will be one component in a broader Estuary Contaminant Index that includes assessments of water, sediments, toxicity, bioaccumulation in fish and wildlife, and biological effects, for both aquatic life and human health. The sediment assessment component will be adopted using the California Sediment Quality Objectives (SQO) framework that is currently being drafted. Since the SQO framework is well developed and reviewed, the tenets of that framework were used in developing the concepts for the WCI. The WCI does not include assessments of human health impacts from water contact or from eating contaminated fish. Those components may be developed in the future. The WCI is not intended for regulatory use, but as an assessment of the condition of the aquatic life resulting from exposure to Estuary water contaminants.

The WCI is described and demonstrated using data from the Regional Monitoring Program. The proposed WCI framework uses three lines of evidence: 1) water contaminant exposure, aquatic toxicity, and potential biological effects. Each line of evidence has four categories (levels) of exposure or effect. The three lines of evidence will be integrated into a Water Contaminant Index designation for each site sampled.

The water exposure line of evidence establishes four levels of contaminant exposure. The widely used and recognized California Toxic Rule (CTR) water quality criteria were used to establish categories of minimal exposure, low exposure, moderate exposure, and high exposure for each individual contaminant. The categories, numbered 1 – 4, were averaged for the 15 contaminants used from each RMP sample to derive an average site exposure assessment. The individual contaminant categories for each site are also presented.

The aquatic toxicity line of evidence also established four levels of toxicity. Using the RMP aquatic toxicity text data, categories of not toxic, low toxicity, moderate toxicity, and high toxicity were established for each of the aquatic toxicity tests used. A toxicity assessment for each sample was determined by integrating the scores from one or two tests performed at each site.

Since there is no information on contaminant effects on plankton or pelagic fish assemblages in the Estuary, the biological effects line of evidence used information from the literature on biological effects thresholds of many of the contaminants measured by the RMP on many Estuary species. Therefore, this LOE assesses the potential for biological effects on Estuary organisms. The number of bioeffects threshold values exceeded in a sample was used to create four categories of potential biological effects: minimal potential, low potential, moderate potential, or high potential.

The assessments from each line of evidence were integrated into an overall WCI determination using a categorization process adopted from the SQO framework. Data from three RMP sites in different parts of the Estuary were used to demonstrate how the WCI procedure would be used to determine a WCI value. Examples of interpretation of the results are also presented. The WCI for each site could be further integrated into an assessment for a water body but a procedure for this step is not presented in this concept.

The WCI concept and demonstration presented in the report are intended to be used as a starting point for further discussion about the WCI. Many of the decisions and methods used need to be reviewed, discussed, and widely vetted among the Estuary's stakeholders, managers, and scientists before the WCI is agreeable and accepted for use in the region, and before an actual Water assessment can be conducted. Thus, modifications and further testing of the WCI are anticipated.

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Introduction and Background

The Regional Monitoring Program (RMP) has been measuring contaminant concentrations and aquatic toxicity in the waters of the San Francisco Estuary since 1993. The results from these measurements are reported annually as status and trends for numerous contaminants that are each compared to regulatory water quality criteria (California Toxics Rule), and as summaries of aquatic toxicity testing (e.g. SFEI, 2005). Owing to the large number of contaminants measured annually at numerous sites, understanding the "big picture" of Estuary contamination may be overwhelming. Providing a clear synthesis of the status and trends of contamination in the Estuary is a RMP Objective. How to provide such a synthesis has been discusses previously as reviewed by Gunther and Jacobson (2002) and Thompson and Gunther (2004). Most recently, The Bay Institute included an assessment of Estuary water contamination in their 2003 Score Card (TBI, 2003).

Building on the use TBI effort, two assessment questions related to Estuary contamination impacts on aquatic life in San Francisco Estuary habitats were proposed by Thompson and Gunther (2004):

- Are Estuary waters and sediments becoming more contaminated?

- Are Estuary waters and sediments harmful to biota?

To address these questions, four kinds of indicators were recommended for use by the San Francisco Estuary Project for assessing contamination in San Francisco Estuary habitats (Thompson and Gunther, 2004):

- Contaminant concentrations
- Incidence of toxicity
- Benthic macrofaunal assessments
- Fish and bird tissue bioaccumulation

These indicators are currently envisioned as components of an Estuary Contamination Index (ECI) that summarizes information about contamination in the region. The ECI should include components that assess the condition of aquatic life and human heath risks from exposure to contaminants.

The objective of this report is to present a concept for, and to demonstrate one component of the ECI, a Water Contamination Index (WCI) that synthesizes and integrates information about exposure to water contamination, aquatic toxicity tests, and potential biological effects into an assessment of possible impacts on aquatic life in the Estuary. The WCI as presented, is considered to be a concept at this time because many of the decisions made in developing the WCI need to be discussed and vetted by Estuary stakeholders, managers, and scientists. Therefore, the WCI proposed in this report should be considered to be a work-in-progress, to be used for discussion towards an agreeable and accepted index.

The WCI does not address human health impacts. That component of the ECI may be developed and presented in the future. A framework showing the components of the ECI, and the status of their development is shown in Table 1. The WCI concept is modeled after the emerging California Sediment Quality Objectives (SQO) framework. Since the SQO framework will probably be used in the Estuary, the WCI is developed with a parallel structure so that the SQO and WCI assessments can be combined for use in the ECI.

Table 1. A Framework for the Estuary Contamination Index. The six indices listed are currently envisioned as components of the ECI.

Proposed Indices	Status
Aquatic Life Indicators	
Water: aquatic life assessment	This Report
Water: fish and wildlife assessment	Needs to be Developed
Sediment: aquatic life assessment	Draft SQO Report
Sediment: fish and wildlife assessment	Draft SQO Report
Human Health Indicators	
Fish consumption, sediment exposure	Draft SQO Report
Fish consumption, water exposure	Needs to be Developed

The California Sediment Quality Objectives Framework

The SQO framework is currently in Draft, and some of the details will most likely be modified in the near future. However, there is general agreement on the principles and components of the SQO framework that will probably be adopted. The SQO focuses on three types of assessments, each addressing a key sediment-related beneficial use:

1. Aquatic life
2. Fish and wildlife
3. Human health from fish consumption

The following principles are used in the SQOs framework:

- Each assessment-type will use multiple lines of evidence. For example, the aquatic life assessment will use indicators of sediment contamination, sediment toxicity, and benthic macrofauna. Multiple lines of evidence are used because no single line of evidence is believed to be adequate because of limitations with interpreting any single line of evidence (e.g. benthos are influenced by more than just contaminants; toxicity may be due to unmeasured contaminants).

- Each assessment-type will include exposure and effects lines of evidence.

- The three lines of evidence are integrated to provide a final assessment. Integrating the lines of evidence weights biological effects.

- Assessments are for a site or a defined location. However, they may be used for water body or regional assessment using sites as replicates.

The San Francisco Estuary Water Contamination Index

The Water Contamination Index (WCI) is designed to assess the condition of aquatic life in the waters of the Estuary. Similar to the SQO framework, the WCI includes three lines of evidence (LOEs): contaminant exposure, aquatic toxicity, and potential biological effects. The details and use of each LOE are described and demonstrated below. These are not independent lines of evidence. Water contamination is expected to influence both aquatic toxicity and biological effects, and toxicity tests should reflect the potential for biological effects. However, since cause-and-effect linkages are only known for a few contaminant effects, it is the weight-of-evidence from the three lines of evidence that create a useful assessment.

Conventional water quality measurements such as, nutrients, dissolved oxygen, suspended sediments, and dissolved organic carbon are not included because those variables are not necessarily considered to be contaminants.

Consistent with the SQO framework, the data used in each LOE is organized into four categories. The use of four categories reflects the fact that there is uncertainty and variation in all water contamination and effects measurements. The categories are established to reflect increasing levels of exposure or effect, not simply either above or below a water quality criterion, toxic or not toxic, etc. Using levels of exposure or effect in each LOE also allows for the integration of the three LOEs to create several categories in the final WCI assessment, providing an assessment of the severity or magnitude of condition. Each step in creating the WCI will be demonstrated using RMP data or information from the literature.

Contaminant Exposure Line of Evidence

This LOE assesses the potential for exposure of biota to harmful concentrations of contaminants. Many of the water contaminants measured by the RMP between 1993 and 2003 (Table 2) were used to demonstrate how this LOE could be created. Those data are available on the SFEI RMP website.

For this demonstration, the currently used water quality criteria for the protection of aquatic life as listed in the California Toxics Rule (CTR; EPA, 2000) were used to provide guidance for the creation of four levels exposure of aquatic life to water contamination. The CTR values used were the four-day average, chronic aquatic life criteria for salt or fresh water (depending on site location). Fifteen of the contaminants that are measured by the RMP have aquatic life criteria (Table 2). There are no such criteria for total DDTs, diazinon, or any PAH compounds. The criterion for mercury is from the Basin Plan (SFBRWQB, 1995), and the criterion for chlorpyrifos is from the U.S. EPA (1999). While these criteria were used to guide the establishment of categories of exposure, the categories are not regulatory, but are used here as descriptive levels of contaminant exposure for aquatic life.

Table 2. Water contaminants measured by the RMP that were used in the Contaminant Exposure and Biological Effects LOEs. For water, the same matrix (dissolved or total) and units as used in the CTR were used. For Bioeffects the matrix and units used were those listed in the ECOTOX data base (EPA, 2005).

Contaminant	Water LOE	Bioeffects LOE
Trace elements		
Ag	X	X
As	X	X
Cd	X	X
Cr	X	X
Cu	X	X
Hg	X	X
Ni	X	X
Pb	X	X
Se	X	X
Zn	X	X
Trace organics		
Acenaphthene		X
Anthracene		X
Benzo(a)pyrene		X
Fluoranthene		X
Pyrene		X
alpha-HCH		X
beta-HCH		X
gamma-HCH		X
Chlordanes	X	
Chlorpyrifos	X	X
Diazinon		X
Dieldrin	X	X
Endrin		X
p,p'-DDD		X
p,p'-DDE		X
p,p'-DDT	X	X
Sum of PCBs	X	

Exposure Categories

Four categories of exposure were established. Each contaminant at each site considered will be placed into one of these categories:

- **Minimal Exposure.** The lowest concentrations in the Estuary, considered to be background or ambient concentrations. This category includes concentrations below minus 10% of the CTR value for each contaminant, assuring that the concentrations are well below levels that may impact aquatic life.

- **Low Exposure.** The concentration is near the CTR criterion, and may slightly exceed it, but is generally within measurement error of the CTR concentration. The range of values is $\pm$ 10% of the CTR value for each contaminant.

- **Moderate Exposure.** Concentrations are clearly above background or ambient concentrations, and clearly above the CTR value. The range of values is 10% above the CTR value to 2 times the CTR value.

- **High Exposure.** Concentrations are significantly above CTR criteria. These high concentrations are present in a small percentage of the samples. The lower threshold value is 2 times the CTR value.

The definition of the Low Exposure category refers to measurement error, and values of +/- 10% and +/- 5% of the CTR value were evaluated. Those values bracket the average error of all contaminant measurements in the RMP where the average 95% confidence interval is approximately 7.5% of the mean. The Moderate - High Exposure threshold was examined using subjective values of 2 times-, or 3-times the CTR guideline. The distributions of the exposure categories that resulted from these various evaluations were very similar. Therefore, the more conservative thresholds of ± 10% of the CTR and 2 times the CTR was selected.

Exposure Assessment

The contaminant exposure assessment results in an exposure category designation for each site sampled. This is accomplished by first calculating a site score for each contaminant on Table 2. The site score is simply the exposure category converted to a number from 1 (Minimal Exposure) to 4 (High Exposure). All individual contaminant scores at each site were averaged. Thus, the contaminant exposure assessment is an average of all individual contaminant category scores at a site. The score is rounded-up as a conservative measure.

Using RMP water contaminant data, the above procedure resulted in the distribution of category scores shown in Figure 1. Nearly all RMP sites were in the Minimal Exposure category. Only seven (3%) of the samples were categorized as having Low Exposure. These results are similar to those shown by the RMP reports since 1993, showing that in general, most water contaminants are very low.

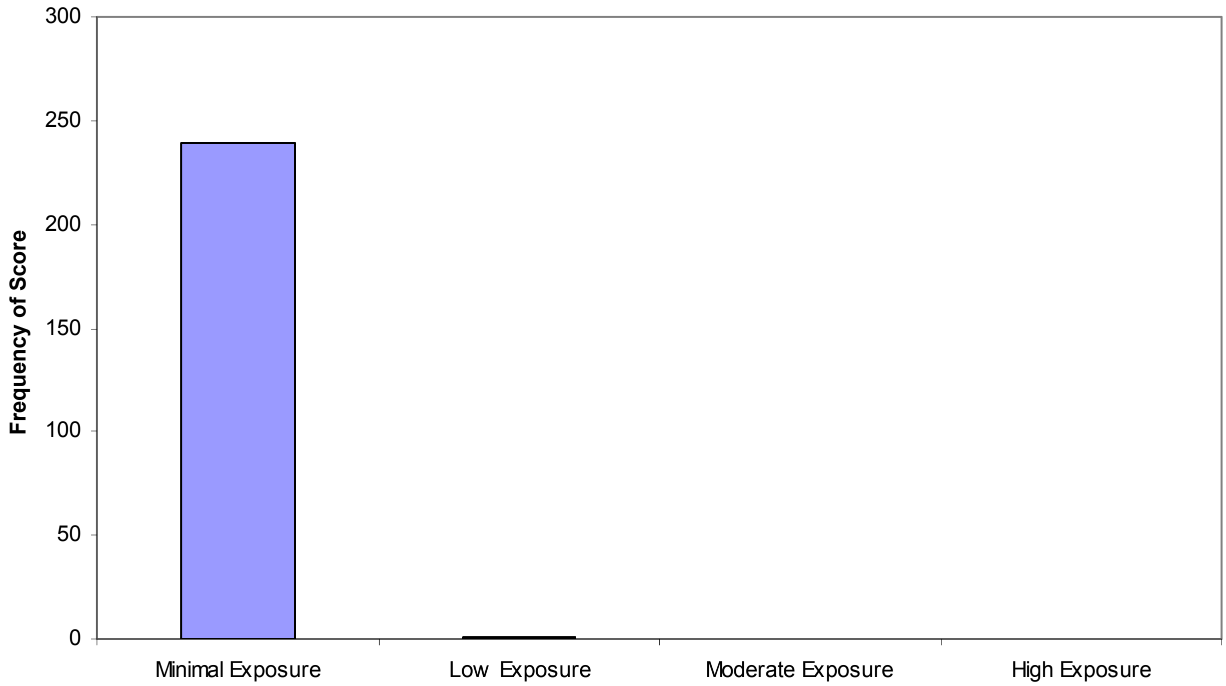

Figure 1. Frequency of contaminant exposure categories from the RMP samples.

Averaging individual contaminant categories provides an overall site exposure assessment specifically for use in the WCI, which will be combined with similar categorical assessments for aquatic toxicity and biological effects. However, averaging the contaminant categories obscures important information about individual contaminants of concern in the Estuary. Therefore, the individual contaminant category designations for each site should be included as part of the contaminant exposure LOE presentation. Figures 2A - C show the contaminant categories at three RMP sites in 1996. Although the average exposure site category was “Low Exposure” at station C-3-0 in the southern sloughs of the Estuary, mercury and DDTs had exposure scores that could affect aquatic life. However, at station BB70 in the Central Bay and BG30 in the mouth of the San Joaquin River, all of the exposure scores were “Minimal”.

Information about several contaminants of concern in the region (e.g. PAHs, pyrethroids) was not included in this LOE as demonstrated. Ideally, information about exposure to all contaminants in the Estuary should be used in this LOE, regardless of CTR usage. This would require data on exposure thresholds for all contaminants, which may not yet exist, but could be developed.

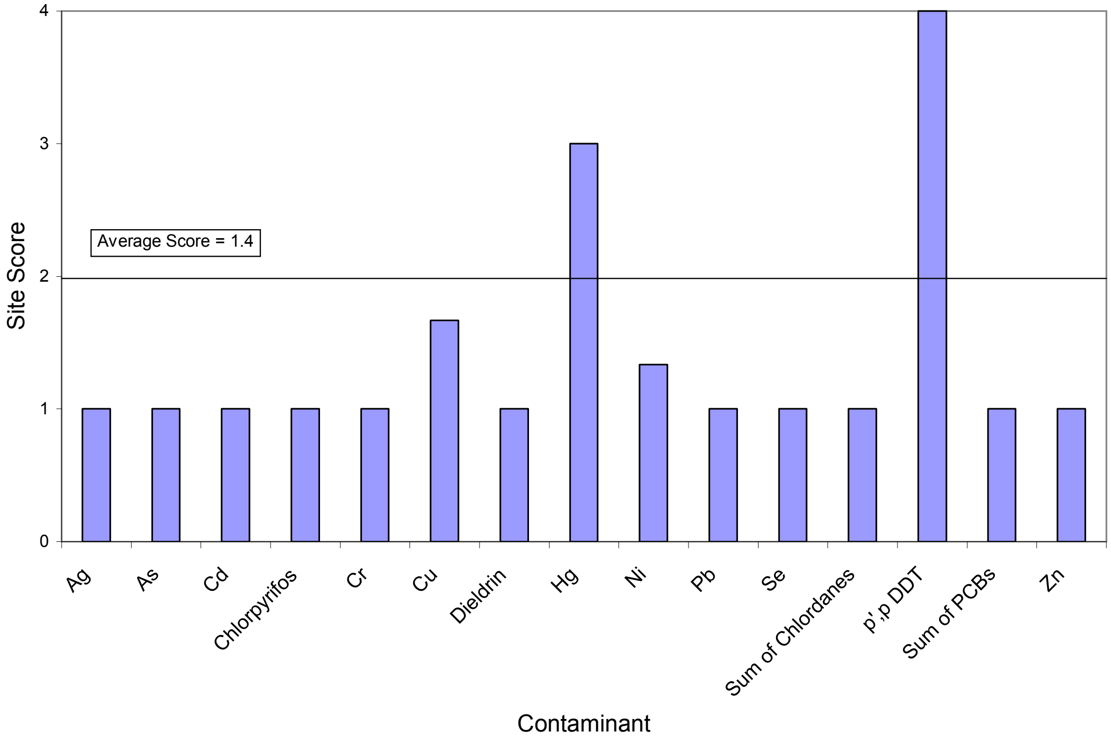

Figure 2a. Contaminant exposure scores for RMP site C-3-0 (Southern Sloughs) in 1996

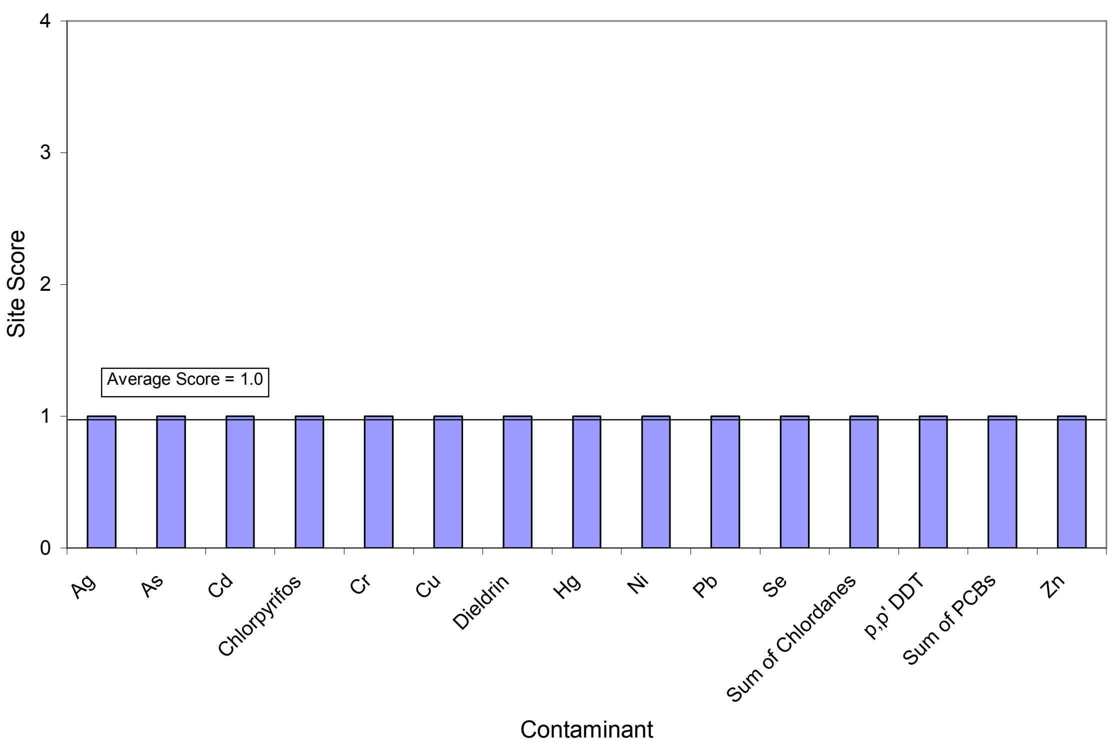

Figure 2b. Contaminant exposure scores for RMP site BB-70 (Central Bay) in 1996.

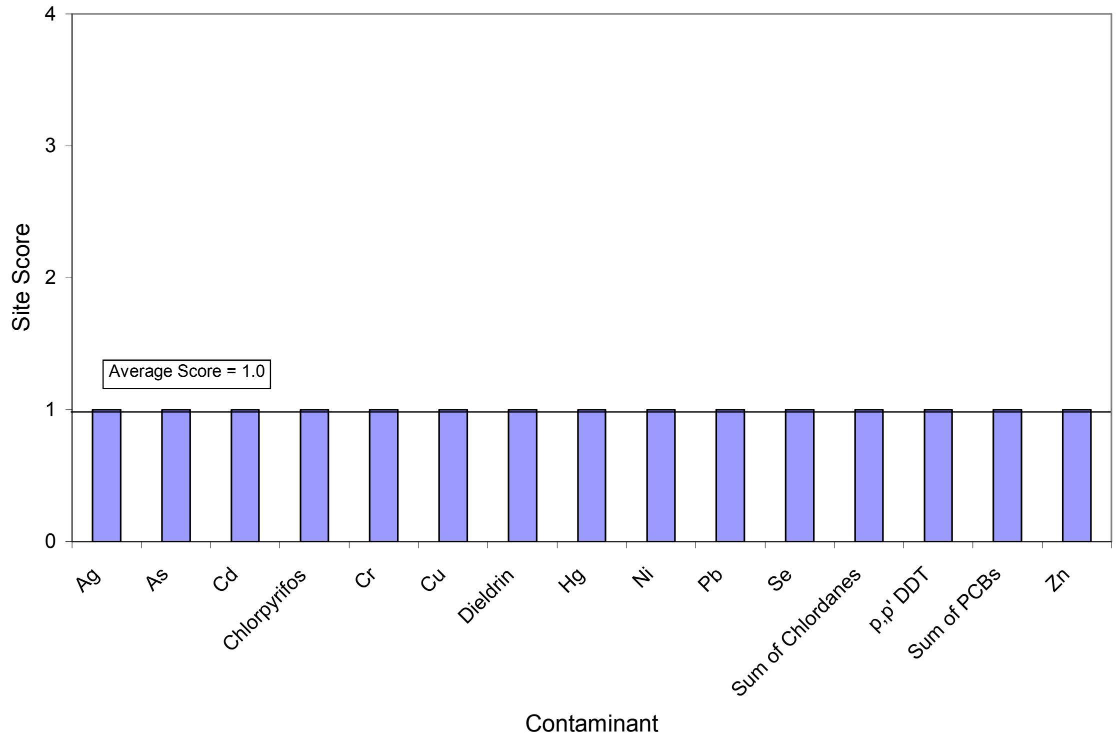

Figure 2C. Contaminant exposure scores for RMP site BG-30 (Rivers) in 1996.

Aquatic Toxicity Line of Evidence

This LOE assesses the toxicity of Estuary water based on laboratory toxicity texts conducted in San Francisco Estuary. It provides evidence that exposure to Estuary water may cause toxicity. The RMP has conducted aquatic toxicity monitoring since 1993 using an evolving series of tests (Table 3). Due to the very low incidence of toxicity at the RMP stations in the early 1990s, routine annual monitoring was gradually reduced, and is currently only conducted every five years. Consequently data for use in the toxicity LOE is not available at all stations where chemical data is available.

Table 3. Aquatic toxicity tests used in the RMP, 1993-2001.

Test Organism	Duration	Endpoint	Reference
Mytilus edulis	48-hour	% Normal Development	ASTM, 1991
Crassostrea gigas	48-hour	% Normal Development	ASTM, 1991
Americamysis bahia	7-day	% Survival	EPA Method 1007
Thalassiosira	96-hour	Cell growth (cell count)	ASTM, 1990

The toxicity of a sample is determined by a significant difference from controls using a t-test. Occasionally, the mean endpoint (e.g. % survival) in the controls is high (>95%) with very small standard error, which can result in statistically significant toxicity even when mean survival in treatments approaches 90%, a situation that most toxicologists agree is not compelling evidence of toxicity.

Categories of Toxicity

Four categories of aquatic toxicity that reflect increasing degrees of toxicity, were established for use in the WCI. The results of the t-tests comparing control and test samples, the lowest control value of all tests for each test-types (Table 4), and subjective professional judgment were used to establish the following four categories of toxicity:

1. **Not Toxic.** Not significantly different from controls AND above the lowest control value for the test-type.

2. **Low Toxicity.** Not significantly different from control AND below the lowest control value, OR significantly different from control and above the lowest control.

3. **Moderate Toxicity**. Significantly different from controls AND below the lowest control value.

4. **High Toxicity.** Below 50% normal development for the molluscan tests, below 47.4% survival for the mysid test (50th percentile of toxic samples), and less than 857500 cells for the diatom test (50% of the mean control value).

Table 4. RMP toxicity test control sample statistics for each test endpoint listed on Table 3

Test	N	Mean	Median	Minimum	Maximum
C. gigas	11	77.28	81.0	70.0	85.0
M. edulis	52	91.8	95.0	71.0	98.0
A. bahia	152	92.7	92.5	80.0	100.0
Thalassiosira	24	1672500	1715000	1040000	2490000

Toxicity Assessment

Each toxicity test at a site is placed into a category as described above, providing a toxicity site assessment. It is common and desirable to conduct at least two toxicity tests on a sample since any single test provides limited information. The RMP typically conducted two toxicity tests on each sample collected, but a single test was conducted at some sites. The aquatic toxicity LOE may use a single test result, or integrate the results of two tests into an overall site toxicity category. Table 5 shows a set of rules for combining the results of two toxicity tests at each site into an overall site category, using the toxicity categories presented above. Where the average category falls between categories the lower category is used as a conservative measure.

Table 5. Toxicity LOE assignment when two toxicity tests are used. Non = nontoxic, Mod = moderate. The category score is converted to a numeric score, in parenthesis.

Test 1	Test 2	Sum	LOE Category
Not (1)	Not (1)	2	Not toxic
Not (1)	Low (2)	3	Low toxicity
Not (1)	Mod (3)	4	Low toxicity
Not (1)	High (4)	5	Low toxicity
Low (2)	Low (2)	4	Low toxicity
Low (2)	Mod (3)	5	Moderate toxicity
Low (2)	High (4)	6	Moderate toxicity
Mod (3)	Mod (3)	6	Moderate toxicity
Mod (3)	High (4)	7	High toxicity
High (4)	High (4)	8	High toxicity

For example at RMP station BA40 in Redwood Creek, sampled in July, 1997:

Test 1: *M. edulis*, 90% mean percent normal development, Category score =Not Toxic.
Test 2: *A. bahia*, 32% mean survival; Category score=High Toxicity.

Therefore, for the two tests, the LOE Category=Low Toxicity. Similar rules have been developed for more than two toxicity tests for SQO and could be applied for sites with more than two toxicity tests.

Most of the RMP samples were not toxic; tests using *C. gigas* (oyster) and *Thalassiosira* (diatom) were never toxic. Only four (5.9 %) of the *M. edulis* (mussel) tests were toxic, but all toxic tests had at least 90% normal development. Twenty-one (13.8 %) of the *A. bahia* (mysid) tests were toxic. The distribution of the toxicity site categories using RMP data show that most samples are Not Toxic, and none are Highly Toxic (Figure 3). This distribution corroborates the results of the analysis of RMP aquatic toxicity data in the Estuary conducted by Ogle *et al*., (2001).

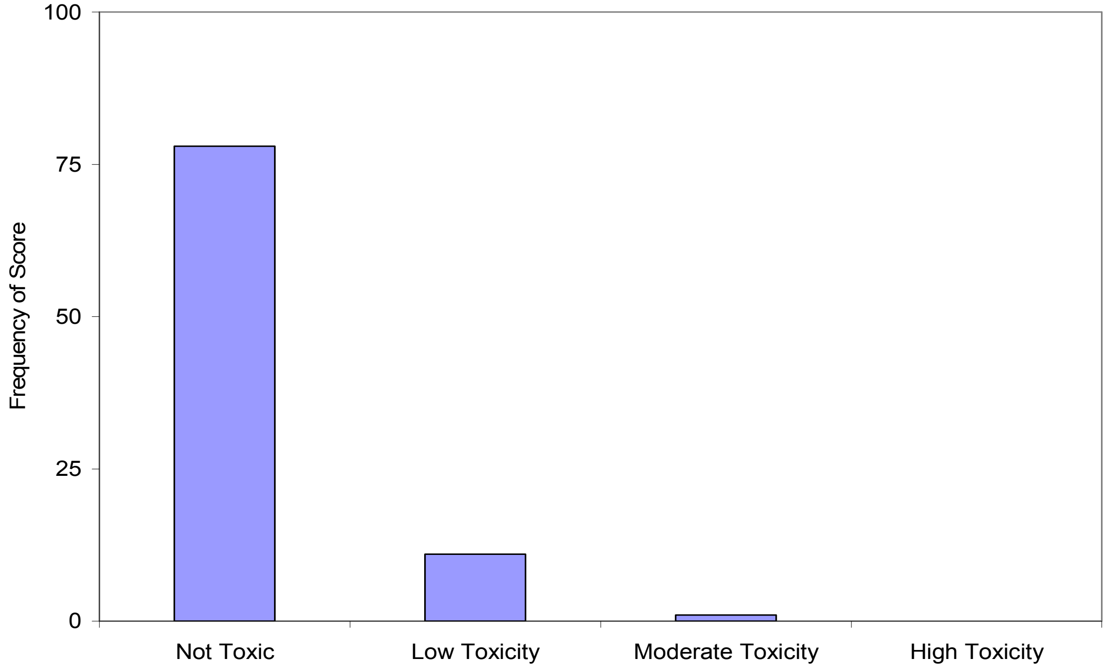

Figure 3. Frequency of aquatic toxicity categories using RMP data.

Biological Effects Line of Evidence

The biological effects LOE assesses the potential for biological effects due to contamination in the Estuary waters. The SQO uses benthic macrofauna assessments for biological effects because there is a large amount of published information relating benthic impacts to sediment contamination. However, no studies have been conducted on the relationships between plankton or pelagic fish communities and contaminant impacts in the Estuary, and a biological community indicator cannot currently be used for this LOE. However, there is a considerable amount of information in the literature about the potential for biological effects of many contaminants of concern on individual organisms (or surrogates) that inhabit the Estuary.

For this demonstration, data on biological effects thresholds for 21 common and abundant species of plankton, benthos, and fish that inhabit the Estuary (Table 6), from exposure to 25 contaminants measured by the RMP (Table 2) were used. This data was compiled from the ECOTOX (effects) database (EPA, 2005). Only the most ecologically relevant information was selected for use from the database, and included information on biochemical, growth, histology, mortality, and reproductive effects. Where there was information from several types of tests for a given contaminant – organism combination, the lowest effect level or the maximum test duration was used as a conservative assumption. Information was available for both freshwater and saltwater organisms. However, information was not available for all Estuary species and contaminants. Thus, although most of the ECOTOX data was derived from laboratory toxicity tests, the biological effects LOE will use the effects threshold information, which distinguishes this LOE from the aquatic toxicity LOE that was based actual tests conducted in the Estuary to determine toxicity using comparisons to controls.

Table 6. Species included in the Biological Effects LOE

Species Name	Faunal Group
Salt Water	
Americamysis bahia	Mysid
Cancer magister	Crab
Clupeidae	Fish
Cymatogaster aggregata	Fish
Engraulidae	Fish
Eurytemora affinis	Copepod
Menidia beryllina	Fish
Mytilus edulis	Mussel
Mytilus galloprovincialis	Mussel
Mytilus sp.	Mussel
Oncorhynchus tshawytscha	Salmon
Oryzias latipes	Fish
Palaemon elegans	Shrimp
Palaemon serratus	Shrimp
Paralichthys olivaceus	Flatfish
Platichthys flesus	Flatfish
Pseudodiaptomus coronatus	Copepod
Fresh Water	
Ceriodaphnia dubia	Arthropod
Hyalella azteca	Amphipod
Morone saxatilis	Striped Bass
Oncorhynchus tshawytscha	Salmon
Oryzias latipes	Fish
Palaemon adspersus	Shrimp
Platichthys stellatus	Flatfish

Categories of Biological Effects

The exceedance of a biological effects threshold value for a given contaminant - species combination in the effects database may be considered to be an indication of the potential for a biological effect on an Estuary species. Four categories of biological effects were established for use in this demonstration:

1. **Minimal Potential.** No biological effect thresholds exceeded. The term “minimal” is used in preference to “no effect” because of the incomplete nature of the effects database and to acknowledge possible impacts due to additive or cumulative effects from mixtures of contaminants.

2. **Low Potential.** One biological effect threshold was exceeded.

3. **Moderate Potential.** More than one biological effects threshold was exceeded. However, none of the RMP samples were in this category using the bioeffects database information.

4. **High Potential.** More than five biological effect thresholds were exceeded. The threshold limits for this category must be reconsidered using more extensive effects information.

Biological Effects Assessment

The distribution of the biological effect categories from the RMP samples is shown on Figure 4, and is similar to the distribution for exposure and toxicity. Most samples did not exceed any of the effects thresholds used, only 20 samples exceeded one threshold, and no samples exceeded more than one threshold. Only two contaminant - species thresholds were exceeded: the diazinon threshold for the amphipod *Hyallela azteca* in freshwater was exceeded in three samples at the RMP river sites where the Delta enters Suisun Bay, and the zinc threshold for the mussel *Mytilus* in freshwater was exceeded in 17 samples from the southern Sloughs in the South Bay.

The biological effects assessment as demonstrated is not comprehensive, as it only includes information for a limited number of contaminants and species in the Estuary. The effects database did not include information on any Estuary species for PCBs, PAHs, or pyrethroid pesticides, which are known contaminants of concern in the Estuary.

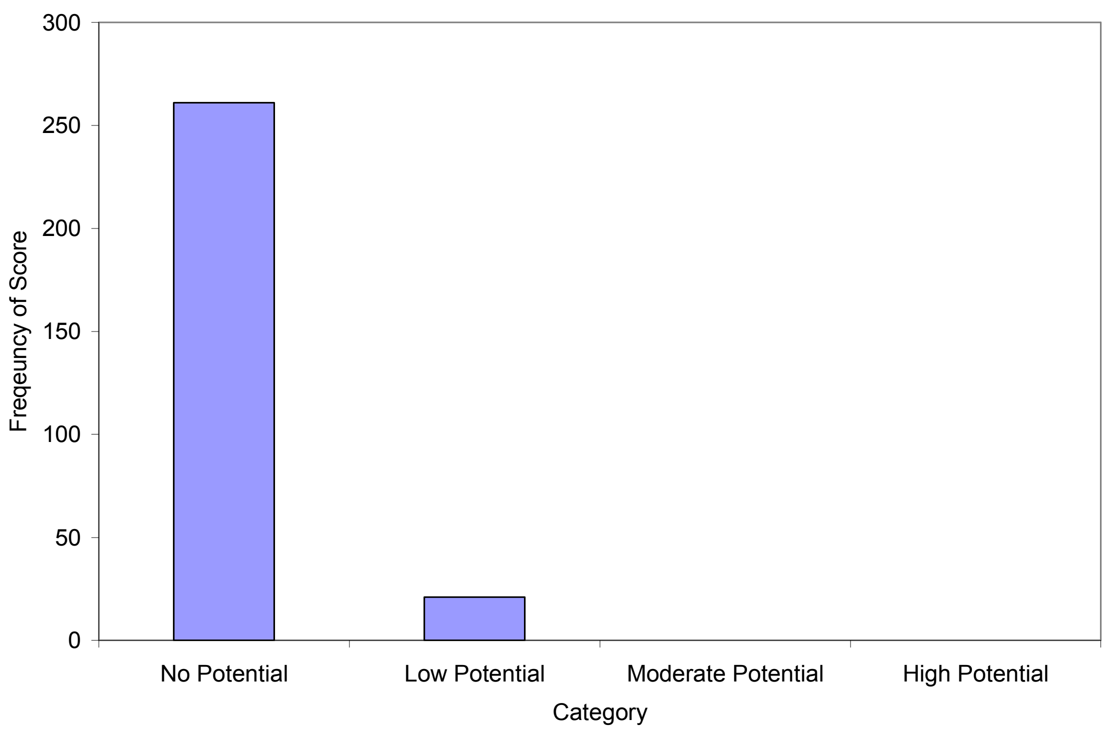

Figure 4. Frequency of biological effects categories using RMP data.

Water Contamination Index: Integration of the Three Lines of Evidence

The basic assessment unit for all three LOEs was a sample from a specific site, and data for each LOE was placed into assigned to a category as described above. Consistent with the SQO framework, the final WCI designation will result from the integration of the categories from each LOE assessment, into one of six final WCI categories for each site:

- Unimpacted
- Likely Unimpacted
- Possibly Impacted
- Likely Impacted
- Clearly Impacted
- Inconclusive

It is expected that there will often be only two LOEs available. For example, aquatic toxicity testing is not conducted on all water samples collected by the RMP. The WCI may be used with two LOEs, but they must include a measure of exposure (contamination) AND effects (toxicity or biological effects). The "inconclusive" category may be used when there are missing lines of evidence, or when the LOEs are highly conflicted and a meaningful assessment cannot be made.

The determination of the final WCI is demonstrated below with examples using data from three RMP sites. A sequential process is used similar to the SQO assessment. First, the Potential for Effects to aquatic life is determined using the toxicity and biological effect LOEs as shown in Table 7. Then, the outcome from that Table is combined with the results of the contaminant exposure LOE to produce the WCI designation (Table 8).

The results from applying the WCI process to three RMP sites from different Estuary regions (water bodies) are shown in Table 9. The Potential for Effects (Table 7) was designated "Unaffected" at all three sites as a consequence of integrating Not Toxic or Low Toxicity categories with the Low or Minimal Potential for biological effects categories. The final WCI assessment for these sites resulted in a designation of "Unimpacted" when the Unaffected Potential for Effect result was integrated with the Minimal Contaminant Exposure category. The demonstration results suggest that there is no impact to aquatic life from exposure to water contaminants at those sites.

Interpretation of these demonstration results should also include discussion of the LOE components. For example, at Site C-3-0: There was no toxicity at the site, but the threshold for zinc effects on mussels was exceeded. However the exposure results only showed elevated risks for mercury and DDT (Figure 2a). At Site BG30, the toxicity category was "Low" based on very different test results (Table 9). But, both exposure and biological effects were "Minimal". One might conclude that the observed severe mysid toxicity results were possibly due to unmeasured contaminants. The inclusion of such short sentences help interpret and understand the assessment results and reconcile differences in individual LOE categories.

Water Body Assessments

As suggested in the Introduction, one of the main reasons to use indices is to simplify large amounts of detailed information into a meaningful summary of condition. The RMP monitors numerous contaminants at many sites annually, and it is not practical to convey the WCI results for each sample in a "State of the Estuary" – type summary report; there is too much information to consider. As determined for the RMP, there are recognized differences in various locations, or water bodies of the San Francisco Estuary (Lowe, *et al.* 2004). Thus, in its final form, the WCI could convey results summarized annually for each Estuary water body. These water body assessments are possible because the RMP currently uses a stratified random sampling design allowing statistically robust conclusions about water body condition to be made. Additionally, guidance for waterbody assessments for 305(b) application is available from the SWRCB.

Water body assessments are not included in this WCI demonstration because such assessments using the WCI for site assessements, as presented, are not yet appropriate.

Table 7. Step 1 in the WCI integration procedure: determine the Potential for Effects to aquatic life.

Toxicity LOE

Biological Effects LOE

	Not Toxic	Low Toxicity	Moderate Toxicity	High Toxicity
Minimal Potential	Unaffected	Unaffected	Unaffected	Low Effect
Low Potential	Unaffected	Low Effect	Low Effect	Low Effect
Moderate Potential	Low Effect	Moderate Effect	Moderate Effect	Moderate Effect
High Potential	Moderate Effect	High Effect	High Effect	High Effect

Table 8. Final Water Contaminant Index Determination.

Potential for Effects

Contaminant Exposure LOE

	Unaffected	Low Effects	Moderate Effects	High Effects
Minimal Exposure	Unimpacted	Likely Unimpacted	Possibly Impacted	Possibly Impacted
Low Exposure	Unimpacted	Possibly Impacted	Possibly Impacted	Likely Impacted
Moderate Exposure	Likely Unimpacted	Possibly Impacted	Likely Impacted	Clearly Impacted
High Exposure	Likely Unimpacted	Likely Impacted	Clearly Impacted	Clearly Impacted

Table 9. Examples of applying the WCI procedure to selected RMP sites.

RMP Estuary Region	Site	Year	Toxicity Result	Toxicity Category	Bioeffects Result # Exc.	Bioeffects Category	Contaminant Exposure Result	Contaminant Exposure Category	Potential for Effects	WCI Result
Southern Sloughs	C-3-0	1996	97% (Mytilus) 100% (Mysid)	Not Toxic	1	Low Potential	Mean Score=1.4	Low Exposure	Unaffected	Unimpacted
Central Bay	BB70	1996	96% (Mytilus) 92% (Mysid)	Not Toxic	0	Minimal Potential	Mean Score=1.0	Minimal Exposure	Unaffected	Unimpacted
Rivers	BG30	1996	96% (Mytilus) 0% (Mysid)	Low Toxicity	0	Minimal Potential	Mean Score=1.0	Minimal Exposure	Unaffected	Unimpacted

Summary and Conclusions

Many of the decisions made, methods used, and details included in the WCI demonstration were based on the SQO development process, and the judgment of the authors. It has been presented as a concept and strawman to stimulate further discussions. To gain acceptance and usage in the region, the WCI must be easily and thoroughly understood, and be useful to stakeholders, permit holders, management and regulatory agencies, and scientists. Therefore, the WCI concept presented should be widely reviewed, discussed, vetted, and subsequently modified before it is ready for use.

The WCI demonstration at three RMP sites suggested that there was little impact on aquaitic life from exposure to water contamination. However, it must be emphasized that the results shown were for demonstration purposes only and may not represent the actual condition at the sites analyzed, or of the Estuary. The WCI is not yet ready for application or usage. It should also be pointed out that water contamination assessments based on human health criteria are known to be very different than for aquatic life, and are currently the focus of TMDLs for several contaminants in the Estuary.

The indicators used for the biological effects LOE need to be reconsidered. The use of the ECOTOX data may overly redundant with the exposure and/or the toxicity LOE. As used in this demonstration, most of the ECOTOX information is based on laboratory toxicity tests that may have been used to derive CTR values. Other options for the biological effects LOE include:

- Use information that is not based on toxicity tests, but on effects thresholds from laboratory or field experiments, biomarkers, etc. that is available in the scientific literature.

- Develop aquatic community indicators (fish or plankton) for San Francisco Estuary.

- Use only two LOEs: the contaminant exposure and aquatic toxicity indicator until an agreeable biological effects indicators are fully developed.

Other elements of the WCI that should be discussed include:

- The choices of category thresholds for each LOE are largely based on professional judgment. These categories could be statistically optimized as has been done for the SQO. This will require further evaluation of the empical relationships between the exposure and effects LOEs, and application of optimization methods. The result categories used to integrate the three LOEs into a final WCI assessment should also be discussed and vetted.

- Water exposure information is needed for all contaminants, not just those for which CTR aquatic life criteria exist, such as PCBs and PAHs. Additionally, information about important contaminants that are not routinely measured by the RMP (e.g. pyrethroids) and provisions for inclusion of other emerging contaminants should be considered.

- Explore the use of CTR quotients (similar to Effects Range ERL, ERM used for sediments), or conversion to toxic units to reflect the additive nature of water contamination. The SQO contaminant exposure LOE is using an additive assessment measure.

- Develop methods for Estuary water body assessments. The SQO framework will develop similar methods and the WCI should be consistent with those recommendations. These methods should be consistent with SWRCB 303(d) guidance.

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ADDENDUM

ADDITIONAL AQUATIC BIOLOGICAL EFFECTS THRESHOLDS FOR SAN FRANCISCO ESTUARY

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This Addendum is for the Draft Report:

Thompson, B., Melwani, A., Lowe, S., Delaney, M., 2006. Concept and Demonstration of A Water Contamination Index For The San Francisco Estuary. Draft report to The San Francisco Estuary Project, The San Francisco Estuary Regional Monitoring Program, Surface Water Ambient Monitoring Program. San Francisco Estuary Institute, Oakland CA. 25 pp.

Introduction

One of the three lines of evidence (LOEs) included in the Draft Water Contamination Index (WCI) was the assessment of the potential for biological effects in the Estuary. This assessment was based on information included in the US EPA's EcoTox database that was edited to only include effects thresholds for species that reside in San Francisco Estuary, and for the contaminant commonly measured by the RMP. The biological effects assessments using the EcoTox data was acknowledged to be incomplete and perhaps somewhat redundant with information used in the aquatic contamination LOE, since much of the EcoTox data was used to derive water quality criteria applicable to the Estuary.

Following the completion of the Draft Water Contamination Index Report, SFEI launched a literature search to find additional information on biological effects thresholds that could augment the EcoTox data for use in future biological effects assessments.

Results

Forty-nine published articles with biological effects thresholds were reviewed. These articles provided a total of 93 threshold values (Table 1). Of these 93 threshold values, 27 were for lethal effects (LC50s, LD50s, etc.), 60 were for sublethal effects, and six were lab studies determining sublethal effects on cell cultures, not whole organisms.

A primary goal of the literature search was to identify studies on biological effects other than toxicity, since the toxicity LOE of the WCI addresses these assessments. Therefore, LC50 studies and lab tests were given a low priority in the search. Studies of mixtures of effluent, and measurements of the levels of contaminants found in fish (often compared to EPA EcoTox thresholds) were also low priority.

Sublethal effects were found for lesions caused by PAH, selenium induced deformities, and olfactory inhibition by copper. Thresholds for reduced locomotion, growth inhibition, and effects on reproductive success for a number of different contaminants and species were also found.

There are probably more studies reported in the literature that may be useful. However, due to the limited time and funding allocated to this additional literature search, the biological effects database probably remains incomplete.

This information could be used to reassess the biological effects LOE described in the Draft Report cited above. This could be a priority for continued development of a San Francisco Estuary Contamination Index in the future. Additionally, organizing the information on San Francisco Estuary species effects thresholds for contaminants of concern, into a formal, searchable database also need to be done.

Table 1. List of biological effects thresholds found in the literature search

Species	Contaminant	Effect	Threshold
fathead minnows	2,3,7,8-TCDD	LC50	1.7ng/L
fathead minnows	2,3,7,8-TCDD	full mortality	6.5ng/L
Neomysis mercedis	thiobencarb	4 day LC sub(50)s	304 ug/L
Neomysis mercedis	thiobencarb	7 day LC sub(50)s	214 ug/L
Neomysis mercedis	thiobencarb	14 day LC sub(50)s	91 ug/L
Neomysis mercedis	molinate	4 day LC sub(50)s	9910 ug/L
Neomysis mercedis	molinate	7 day LC sub(50)s	2530 ug/L
Neomysis mercedis	molinate	14 day LC sub(50)s	820 u g/L
Pacific herring larvae	tPAH	NOEC	0.2ug/L, 0.01ug/g
Brown bullhead	BaP	liver and skin neoplasms	10% incidence of liver cancer at 8ug/g PAH; 22-39% incidence at 20-40ug/g PAH
rainbow trout	endosulfan	LC50 & EC50 for cortisol disruption	405uM, 38uM
rainbow trout	diazinon	LC50 & EC50	305uM, 233uM
rainbow trout	manocozeb	LC50 & EC50	>5000 uM, 312uM
rainbow trout	atrazine	LC50 & EC50	>50,000um, >50,000uM
coho salmon	zinc	reduced growth, increased feeding	1900ppm (diet)
Neomysis mercedis	methyl parathion	96-hr LC50	.20ug/L
Neomysis mercedis	malathion	96-hr LC50	2.2ug/L
Neomysis mercedis	carbofuran	96-hr LC50	14ug/L
Neomysis mercedis	copper sulfate	96-hr LC50	150ug/L
Neomysis mercedis	thiobencarb	96-hr LC50	280ug/L
Neomysis mercedis	molinate	96-hr LC50	1600ug/L
Dungeness Crab	carbofuran	inhibited swimming ability	1.5ppb
Dungeness Crab	carbofuran	prevents metamorphosis/ inhibits molting	1.0ppb
Pacific Herring eggs	PAH	malformations, genetic damage, mortality, growth and swimming inhibition	0.7ppb
Pacific Herring eggs	PAH	LOEC: yolk sac edema and immaturity	0.4ppb

pink salmon	weathered crude oil	LOEC	1.0 ppb
Pacific Herring eggs	weathered crude oil	detriment to developing embryoa	9 ug/L
Pacific Herring	weathered crude oil	effects on progeny	58ug/L
pink salmon	crude oil	LOEC	0.94ug/L
fathead minnow embryo/larvae	naphthalene	significant reduction in growth	.85mg/L
fathead minnow embryo/larvae	naphthalene	NOEC	.45mg/L
fathead minnow	naphthalene	LC50	7.9mg/L
rainbow trout	naphthalene	LC50	1.6mg/L
fathead minnow	benzene	LC50	>15.1mg/L
rainbow trout	benzene	LC50	5.3mg/L
Sacramento splittail	selenium	induced atresia	17.3ug/g in food
Sacramento splittail	selenium	induced atresia	6.5ug/g in ovaries
rainbow trout	endosulfan	EC50: inhibition of cortisol secretion	0.19mM
fathead minnow	Cu	IC25 (inhibition conc)	103mg/L
fathead minnow	Diazinon	IC25 (inhibition conc)	1176ug/L
dungeness crab larvae	Arsenic	96hr LC50s	232 ug/l
pacific oyster	Arsenic	48 hr LC50	326 ug/l
Eurytemora affinis	17b estradiol	NOEC (effects on reproductive output/ naupliar development)	674mg/L
Eurytemora affinis	nonylphenol	NOEC (effects on reproductive output/ naupliar development)	773mg/L
Eurytemora affinis	benzo(a)pyrene	NOEC (effects on reproductive output/ naupliar development)	1273mg/L
Eurytemora affinis	di(ethyl-hexyl)-phthalate	NOEC (effects on reproductive output/ naupliar development)	109729mg/L
Platylnereis dumerilii	tri-n-butyltin	LC50	1.34ug/L
rainbow trout	BaP	insufficient yolk sac, kyphosis, absence or abnormality of eyes	0.21ppb

chinook salmon	Cu	impairment of olfactory receptors	50ug/L
rainbow trout	Cu	impairment of olfactory receptors	200ug/L
chinook salmon	Cu	lack of avoidance response	44ug/L
rainbow trout	Cu	lack of avoidance response	180ug/L
English sole	PAH	lesions	54-2800ppb (depending on "lesion category")
English sole	BaP	reduced hatching success	4.0mg (diet)
rainbow trout alvins	BaP	reduced mitosis in brain	0.21ng/ml
carp	methidathion	ACh inhibition	2mg/L
topsmelt	Ni	96h LC50	26560ug/L
topsmelt	Ni	LOEC	4270ug/L
coho salmon	carbofuran	EC50:decrease in olfactory function, change in AChE levels	10.4ug/L
coho salmon	IPBC	EC50:decrease in olfactory function, change in AChE levels	1.28ug/L
coho salmon	mancozeb	EC50:decrease in olfactory function, change in AChE levels	2.05mg/L
Mytilus edulis	tributyltin	increased induction of sister chromatid exchanges and chromosomal abnormalities	.54ug/l
Mytilus edulis	tributyltin oxide	increased induction of sister chromatid exchanges and chromosomal abnormalities	.56ug/L
Platylnereis dumerilii	tributyltin oxide	increased induction of sister chromatid exchanges and chromosomal abnormalities	.32ug/L
English sole	PAH	liver lesions, DNA adduct, growth inhibition	1000ppb
rainbow trout	Cd	EC50: inhibition of cortisol secretion	0.09mM
Pacific herring eggs	crude oil	lesions <24hr after hatching	.48mg/L
juvie chinnok salmon	total PCB	sublethal effects	2.4ug PCB/g lipid
juvie chinnok salmon	total PCB		225ng/g dry weight
juvie salmon	tributylin	protective sediment concentration	6000ng/g
English sole	total AH	hepatic lesions	940ppb
English sole, white croaker, starry flounder	tPAH	"significant chemical effects threshold"	500-1000ppb

Daphnia magna	chlorpyrifos	LD50	6.5 hrs at 1ug/L
Daphnia magna	chlorpyrifos	LD50	12.2hr at 0.5ug/L
Daphnia magna	chlorpyrifos	LD50	48hr at .25ug/L
striped bass	tributyltin	affects gillATPase activity	10ug/L
striped bass	tributylin	concentration dependant changes in morphometry	>0.067ug/L
common carp	TCDD	IC50; inhibition of E2 induced vitellogenesis	0.01 nM
common carp	PCB126	IC50; inhibition of E2 induced vitellogenesis	0.4nM
mosquito fish	chlorpyrifos	LOEC: reduced locomotor behavior	60ug/L
mosquito fish	chlorpyrifos	LC50	20.49mg/L
juvie coho salmon	Cu	EC20 for olfactory inhibition	4.4ug/L
juvie coho salmon	chlorpyrifos	EC20 for olfactory inhibition	.72ug/L
rainbow trout fry	TCDD	leukopenia and thrombocytopenia	1ug/kg
rainbow trout fry	TCDD	Gross and microscopic lesions	10ug/kg
juvie white sturgeon	selenium	reduced swimming and growth	41.7ug/g
juvie white sturgeon	selenium	histopathic alterations in kidney and liver	20.5ug/g
white sturgeon	didecyldimethylammonium chloride	LC50s	varied with age, see text
Sacramento splittail	selenium	skeletal deformities, etc	5mg/L
Sacramento splittail	selenium	deformities	2.7mg/kg at 5mo, 0.7mg/kg at 9mo,
Rainbow trout	2,3,7,8-TCDD	growth inhibition & 20% mortality	5ug/kg
rainbow trout larvae	SeMe	LOEC: decrease in body weight and fork length	4.6ug/g diet
rainbow trout larvae	SeMe	LOEC: decrease in body weight and fork length	1.2ug/g body burden

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