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Incidence of Adverse Biological Effects within Ranges of Chemical Concentrations in Marine and Estuarine Sediments

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ABSTRACT

Matching biological and chemical data were compiled from numerous modelling, laboratory and field studies performed in marine and estuarine sediments. Using

*The methods and guidelines presented in this report do not necessarily represent the policy of the National Oceanic and Atmospheric Administration, Environment Canada, or Florida Department of Environmental Regulation.

these data, two guideline values **(an Effects Range-Low and an Effects Range-Median)** were determined for nine trace metals, total PCBs, two pesticides, thirteen polynuclear aromatic hydrocarbons (PAHs), and three classes of PAHs. The two values defined concentration **ranges that were** (1) rarely, (2) occasionally, or (3) frequently associated with adverse effects. The values generally agreed within a factor of 3 or less with those developed with the same methods applied to other data and to those developed with other effects-based methods. The incidence of adverse effects was quantified within each of the three concentration ranges as the number of cases in which effects were observed divided by the total number of observations. The incidence of effects increased markedly with increasing concentrations of all of the individual PAHs, the three classes of PAHs, and most of the trace metals. Relatively poor relationships were observed between the incidence of effects and the concentrations of mercury, nickel, total PCB, total DDT and p,p'-DDE. Based upon this evaluation, the approach provided reliable guidelines for use in sediment quality assessments. This method is being used as a basis for developing National sediment quality guidelines for Canada and informal, sediment quality guidelines for Florida*.

Keywords: Sediment quality guidelines, Contaminants, Biological effects, Marine, Estuarine. Running Heading: Sediment quality guidelines.

INTRODUCTION

Chemical analyses indicate that coastal sediments in some areas of North America are contaminated (Bolton et al., 1985; O'Connor, 1991; U.S. NOAA, 1991; Wells and Rolson, 1991; Goyette and Boyd, 1989). However, data on the mixtures and concentrations of contaminants in sediments, alone, do not provide an effective basis for estimating the potential for adverse effects to living resources. Interpretive tools, also, are needed to relate ambient sediment chemistry data to the potential for adverse biological effects. A variety of biological measures (including toxicity and/or bioaccumulation tests) can be performed to determine the biological significance of sediment-associated contaminants (Burton, 1992). Also, numerical, effects-based, sediment quality guidelines can be used as screening tools to evaluate sediment chemistry data and to identify and prioritize potential problem areas (Di Toro et al., 1991; Persaud et al., 1992; MacDonald, 1992; Long and Morgan, 1990; Smith and MacDonald, 1992; U. S. EPA, 1989a, 1992a). In this respect, effects-based guidelines can be used to help identify those areas in which the potential for biological effects is greatest.

A variety of biological effects-based approaches to the development of sediment quality guidelines have been developed by many investigators (U. S. EPA, 1989a, 1992a; Adams et al., 1992; Chapman, 1989; MacDonald et al., 1992). These approaches can be grouped into three categories: equilibrium-partitioning modelling, laboratory bioassays, and field studies. Each approach has particular strengths and weaknesses and each defines guidelines in different ways. Thus far, there is no general agreement as to which approach will provide the most reliable, flexible, and credible guidelines for evaluating sediment quality. Nonetheless, sediment quality guidelines derived from the use of multiple methods have been recommended for a broad range of applications (Adams et al., 1992; U. S. EPA, 1989b; Lorenzato et al., 1991).

Using data available from all the major approaches to the development of effects-based criteria, Long and Morgan (1990) prepared informal guidelines for use by the National Oceanic and Atmospheric Administration (NOAA). Subsequently, the database with which these values were prepared was updated and expanded and the approach was refined (MacDonald, 1992; Smith and MacDonald, 1992). In both the NOAA (Long and Morgan, 1990) and Florida (MacDonald, 1992) studies, two guideline values were developed for each chemical. These values defined three ranges in chemical concentrations that were anticipated to be (1) rarely, (2) occasionally, or (3) frequently associated with effects. The identification of ranges in chemical concentrations has been recommended in the development of sediment quality criteria (U. S. EPA, 1992b).

The objectives of the present study are: (1) to present updated values based upon the expanded database; (2) to quantify the percent incidence of adverse biological effects associated with the guidelines; and (3) to compare the guidelines with those developed with other data or methods. In this paper we determined the percent incidence of effects as a measure of the "accuracy" of the guidelines.

METHODS

The methods used in this study have been described in detail (Long and Morgan, 1990; MacDonald, 1992; Smith and MacDonald, 1992; Long, 1992) and will be only summarized here. Sediment chemistry and biological effects data from numerous reports were assembled to support the derivation of the guidelines. The database used by Long and Morgan (1990) was **refined by excluding data from freshwater studies and including** data from additional sites, biological test endpoints, and contaminants (MacDonald, 1992; Smith and MacDonald, 1992). Briefly, the approach involves three steps:

(1) assemble, evaluate, and collate all available information in which measures of adverse biological effects and chemical concentrations in sediments were reported;

(2) identify the ranges in chemical concentrations that were rarely, occasionally, or frequently associated with effects; and

(3) determine the incidence of biological effects within each of the ranges in concentrations for each chemical as an estimate of guidelines accuracy.

Development of a Biological Effects Database for Sediments. A Biological Effects Database for Sediments (BEDS) was developed to compile and integrate chemical and biological data from numerous studies conducted throughout North America. Nearly 350 publications were reviewed and screened for possible inclusion in the BEDS. Data from equilibrium-partitioning modelling, laboratory spiked-sediment bioassays, and field studies of sediment toxicity and benthic community composition were critically evaluated. Only matching, synoptically-collected biological and chemical **data** from marine and estuarine studies were included in the database. Data were excluded if the methods were not clearly described. If there was less than a 10-fold difference in the concentrations of all contaminants among sampling stations, all data from that particular field study were excluded. **The 10-fold criterion was selected to reflect order-of-magnitude contaminant gradients.** Data were excluded if sediments were frozen before toxicity tests were initiated or if toxicity of controls were higher than commonly acceptable. Also, data were excluded if the chemical analytical procedures were inappropriate for determining total concentrations in bulk sediments; for example, trace metals data were excluded if strong acid digestions were not used. The majority of the data sets that were excluded were those in which either no biological data or no chemical data were reported. A total of 89 reports met all the screening criteria and were included in the BEDS. The screening criteria and their use were described previously (MacDonald, 1992; Smith and MacDonald, 1992). The potential weaknesses of using data "encountered" from many different studies have been described (Long, 1992).

The data entered into the BEDS were expressed on a dry weight basis, since only a small minority of the reports included measures of factors that are thought to control bioavailability (e.g., grain size, total organic carbon, acid-volatile sulfides). Equilibrium-partitioning concentrations (U. S. EPA, 1988), if expressed in units of organic carbon, were converted to units of dry weight, assuming a total organic carbon (TOC) concentration of 1.0%. **These conversions were based upon a TOC concentration of 1%, since the overall mean TOC concentration in the BEDS is 1.2%.** Data from spiked-sediment bioassays were incorporated directly into the BEDS.

Apparent Effects Thresholds (AET, Barrick et al., 1988) and National Screening Level Concentrations (SLC, Neff et al., 1986) were entered into the BEDS as reported. Both methods were based upon evaluations of large, merged data sets from multiple surveys. **By merging data from multiple surveys, extremely high and extremely low concentrations in some parts(s) of the study area may be ameliorated by highs and lows in other regions, resulting in intermediate average concentrations.** Raw data from other individual field surveys that passed the initial screening steps were evaluated in "co-occurrence analyses" with either of two methods (Long, 1992). If the statistical significance of the data was reported, then the mean chemical concentrations in the statistical groups (i.e., toxic and non-toxic) were compared. If no such statistical evaluations were reported, the frequency distributions of the biological data were examined, and mean concentrations in subjectively determined groups of samples were compared (e.g., most toxic versus least toxic). **The extreme high and low concentrations reported in individual studies, generally performed over relatively small spatial scales, were not masked by merging data from other studies**.

The kinds of adverse effects included in the BEDS were: (1) measures of altered benthic communities (depressed species richness or total abundance), significantly or relatively elevated sediment toxicity, or histopathological disorders in demersal fish observed in field studies; (2) EC50 or LC50 concentrations determined in laboratory bioassays of sediments spiked with single compounds or elements; and (3) toxicity predicted by equilibrium-partitioning models. To maximize the broad applicability of the guidelines, a wide variety of measures of adverse biological effects was included in the BEDS. All of the measures of effects were treated as if equivalent. However, by screening prospective data sets and including only those biological data that were in concordance with chemical gradients, insensitive measures of effects were excluded. Each entry was assigned an "effects/no-effects" descriptor. An entry was assigned an "effects" descriptor (identified with an asterisk in the data tables) if (1) an adverse biological effect, such as acute toxicity, was reported and (2) concordance was apparent between the observed biological response and the measured chemical concentration.

The documentation supporting each BEDS record included the citation, the type of test or biological effect observed or predicted, the approach that was used, the study area, the test duration (if applicable and reported), the species tested or the benthic community considered, the total organic carbon (TOC) and acid-volatile sulfide (AVS) concentrations (if reported), and the chemical concentration.

In our co-occurrence analyses of field-collected data entered into BEDS, an "effects" descriptor was assigned to data entries in which adverse biological effects were observed in association with at least a two-fold elevation in the chemical concentration above reference concentrations. Either "no gradient", "small gradient" or "no concordance" descriptors were assigned when no differences between stations were reported in the concentration of the chemical of concern; or when mean chemical concentrations differed by less than a factor of two between the groups of samples; or when there was no concordance between the severity of the effect and the chemical concentration, respectively. In these cases, we assumed that other factors (whether measured or not) were more important in the etiology of the observed effect than the concentration of the contaminant considered. Finally, a "no effects" descriptor was applied to biological data from background, reference, or control conditions.

Collectively, the "effects" data sets from the modelling, laboratory, and field studies were **assigned an asterisk in the ascending tables and** used to derive the guidelines. All of the "effects" data were given equal weight in the guidelines derivation. Collectively, data assigned "no gradient", "small gradient", "no concordance", and "no effects" descriptors were regarded as the "no-effects" data set.

Derivation of the Sediment Quality Guidelines. For each chemical, the data from BEDS were retrieved and arranged in ascending order of concentration in a tabular format. These ascending data tables, as reported by Long and Morgan, (1990) and updated by MacDonald (1992) and Smith and MacDonald (1992), summarized the available information for each chemical or chemical group that was considered.

The distributions of the effects data were determined using percentiles (Byrkit, 1975). Two values were derived for each chemical or chemical group. The lower 10th percentile of the effects data for each chemical was identified and referred to as the Effects Range-Low (ERL). The median, or 50th percentile, of the effects data was identified and referred to as the Effects Range-Median (ERM). Percentiles of aquatic toxicity data were used by Klapow and Lewis (1979) to calculate marine water quality standards; the authors noted that this approach tended to minimize the influence of single (potentially outlier) data points on the development of guidelines. Environment Canada and Florida Department of Environmental Regulation used a slight modification to this method, the rationale for which has been documented (MacDonald, 1992; Smith and MacDonald, 1992).

Determination of Percent Incidence of Adverse Biological Effects. The two guideline values, the ERL and the ERM, delineate three concentration ranges for a particular chemical. The concentrations below the ERL value represent a "Minimal-effects" range; a range intended to estimate conditions in which effects would be rarely observed. Concentrations equal to and above the ERL and below the ERM represent a "Possible-effects" range within which effects would occasionally occur. Finally, the concentrations equivalent to and above the ERM value represent a "Probable-effects" range within which effects would frequently occur. The incidence of adverse effects within each range was quantified by dividing the number of "effects" entries by the total number of entries and expressed as a percent. The ERL and ERM values were derived with only the "effects" data set, whereas the calculations of percent incidence of effects independently were based upon both the "effects" and "no-effects" data sets.

An evaluation of the reliability of any proposed guidelines is essential to determine their applicability in sediment quality assessments. In this study, the reliability of the guidelines for each chemical was considered to be relatively high when: (1) they agreed closely (within factors of 3.0 or less) with those developed with other methods and/or with guidelines developed with the same methods applied to different data; (2) the incidence of effects was low (<25%) in the **minimal-**effects ranges; (3) the incidence of effects increased consistently and markedly in concordance with increasing chemical concentrations; and (4) the incidence of effects was very high (>75%) in the probable-effects ranges. The reliability of the guidelines that failed to meet these evaluation criteria was considered to be lower.

RESULTS

ERL and ERM values were derived for 28 substances: 9 trace metals, total PCBs, 13 individual polynuclear aromatic hydrocarbons (PAHs), 3 classes of PAHs (total low molecular weight, total high molecular weight, and total PAH), and 2 pesticides (p,p'-DDE and total DDT). The data available for acenaphthene and phenanthrene are shown in Tables 1 and 2, respectively, to illustrate the format and content of the ascending tables with which the guidelines were derived. **Space limitations preclude inclusion of equivalent tables for all of the substances.**

Adverse effects measured in association with acenaphthene included high amphipod mortality in sediment toxicity tests, low species richness in benthic communities, high prevalence of liver lesions in demersal fish, and chronic toxicity predicted by an equilibrium-partitioning model (Table 1). **No data from spiked-sediment bioassays were available. As an example of the kinds of data analyses that were performed for entry into the BEDS, matching sediment chemistry and amphipod mortality data from Commencement Bay (WA) were evaluated in a co-occurrence analysis. In the samples that were the least toxic to amphipods (12.5±4.5% mortality), the average concentration of acenaphthene was 85.9 ppb. This data entry was assigned a "no-effects" descriptor (ne). In samples that were moderately toxic (26±5.2% mortality), the average concentration of acenaphthene was 127 ppb. The ratio of 127 ppb to 85.9 ppb was less than 2.0, therefore, the**

Table 1. A summary of the available data on the effects of sediment associated acenaphthene (ppb) in coastal sediments.

Concentration (± SD)	Area	Analysis Type	Test Duration	Endpoint Measured	Species	Life Stage	Effects/ No Effects	TOC (%)	Reference
1	Puget Sound, WA	COA		Low prevalence of hepatic cellular alterations (0%)	Parophrys vetulus (English sole)	ADT	NE		1
1	Puget Sound, WA	COA		Low prevalence of hepatic lesions (0%)	Parophrys vetulus (English sole)	ADT	NE		1
1	Puget Sound, WA	COA		Low prevalence of hepatic idiopathic lesions (32.5%)	Parophrys vetulus (English sole)	ADT	NE		1
<3	Halifax Harbour, NS	COA	10-d	Significantly toxic (61.7±12.5% mortality)	Rhepoxynius abronius (amphipod)	ADT	NC		2
<3.5 ±1	Halifax Harbour, NS	COA	10-d	Not significantly toxic (5.2±3.5% mortality)	Corophium volutator (amphipod)	ADT	NE		2
<3.5 ±1	Halifax Harbour, NS	COA	20-d	Not significantly toxic (1±2% mortality)	Neanthes sp. (polychaete)	JUV	NE		2
3.92 ± 1.59	Southern California	COA	10-d	Significantly toxic (51.7% mortality)	Grandidierella japonica (amphipod)	JUV	NC		3
<5	Halifax Harbour, NS	COA	10-d	Not significantly toxic (3% mortality)	Rhepoxynius abronius (amphipod)	ADT	NE		2
<5	Sidney Tar Pond, NS	COA	10-d	Not significantly toxic (4% mortality)	Corophium volutator (amphipod)	ADT	NE		2
<5	Sidney Tar Pond, NS	COA	10-d	Not significantly toxic (3% mortality)	Rhepoxynius abronius (amphipod)	ADT	NE		2
6.92±11.8	Southern California	COA	10-d	Not significantly toxic (23.2% mortality)	Grandidierella japonica (amphipod)	JUV	NE		3
<8.8±5.3	Sidney Tar Pond, NS	COA	20-d	Not significantly toxic (8±5.66% mortality)	Neanthes sp. (polychaete)	JUV	NE		2
9	San Francisco Bay, CA	AETA	48-h	San Francisco Bay AET	Oyster, mussel	LAR	*		4
<12.5	Sidney Tar Pond, NS	COA	10-d	Significantly toxic (100% mortality)	Corophium volutator (amphipod)	ADT	*		2
<12.5	Sidney Tar Pond, NS	COA	10-d	Significantly toxic (100% mortality)	Rhepoxynius abronius (amphipod)	ADT	*		2
16	California	AETA	48-h	California AET	Mytilus edulis (bivalve)	LAR	*		5
16				**ER-L (10th percentile)**					
16	California	AETA		California AET	Benthic species		*		5
16	Northern California	AETA		Northern California AET	Benthic species		*		5
<23.5	Sidney Tar Pond NS	COA	20-d	Significantly toxic (52% mortality)	Neanthes sp. (polychaete)	JUV	*		2
<30.8±25.6	Halifax Harbour, NS	COA	10-d	Not significantly toxic (6.8±7.31% mortality)	Rhepoxynius abronius (amphipod)	ADT	NE		2
<30.8±25.6	Halifax Harbour, NS	COA	10-d	Not significantly toxic (8.5±6.06% mortality)	Corophium volutator (amphipod)	ADT	NE		2
<30.8±25.6	Halifax Harbour, NS	COA	20-d	Not significantly toxic (0.7±1.63% mortality)	Neanthes sp. (polychaete)	JUV	NE		2
50	Burrard Inlet, BC	SQO		Sediment quality objectives	Aquatic biota		NE		6
56	Northern California	AETA	10-d	Northern California AET	Rhepoxynius abronius (amphipod)	ADT	*		5
56	California	AETA	10-d	California AET	Rhepoxynius abronius (amphipod)	ADT	*		5
56	San Francisco Bay, CA	AETA	10-d	San Francisco Bay AET	Rhepoxynius abronius (amphipod)	ADT	*		4
56.7±70	Commencement Bay, WA	COA	48-h	Least toxic (15.1±3.1% abnormality)	Oyster	LAR	NE		7
63	Puget Sound, WA	AETA		PSDDA screening level concentration	Aquatic biota		NE		8
85.9±97	Commencement Bay, WA	COA	10-d	Least toxic (12.5±4.5% mortality)	Rhepoxynius abronius (amphipod)	ADT	NE		7
119±105	Commencement Bay, WA	COA	48-h	Moderately toxic (23±2.3% abnormality)	Oyster	LAR	*		7
127±117	Commencement Bay, WA	COA	10-d	Moderately toxic (26±5.2% mortality)	Rhepoxynius abronius (amphipod)	ADT	SG		7
150	Eagle Harbor, WA	COA	4-d	LC50	Rhepoxynius abronius (amphipod)	ADT	*		9
160	Puget Sound, WA	SQG		Chemical criteria	Benthic community		*	1	10
247±147	Burrard Inlet, BC	COA	10-d	Not toxic (4.5±3.02% emergence)	Rhepoxynius abronius (amphipod)	ADT	NE	2.66±2.15	11
247±147	Burrard Inlet, BC	COA	10-d	Not toxic (5.21±3.61% emergence)	Corophium volutator (amphipod)	ADT	NE	3.18±2.1	11
283±140	Burrard Inlet, BC	COA	10-d	Not toxic (97.2±2.84% reburial)	Rhepoxynius abronius (amphipod)	ADT	NE	2.8±1.96	11
283±140	Burrard Inlet, BC	COA	10-d	Not toxic (8.9±2.99% mortality)	Corophium volutator (amphipod)	ADT	NE	2.8±1.96	11
293±73.8	Elizabeth River, VA	COA	96-h	No significant change in respiration rate	Palaemonetes pugio (grass shrimp)	ADT	NE		12
306±604	Commencement Bay, WA	COA	48-h	Highly toxic (44.5±19% abnormality)	Oyster	LAR	*		7
350±45.8	Burrard Inlet, BC	COA	10-d	Not toxic (7.9±5.12% mortality)	Rhepoxynius abronius (amphipod)	ADT	NE	2.64±2.14	11

Table 1 cont.

Concentration (± SD)	Area	Analysis Type	Test Duration	Endpoint Measured	Species	Life Stage	Effects/ No Effects	TOC (%)	Reference
390	Burrard Inlet, BC	COA	10-d	Highly toxic (30.5% emergence)	Rhepoxynius abronius (amphipod)	ADT	SG	3.5	11
390	Burrard Inlet, BC	COA	10-d	Highly toxic (23% emergence)	Corophium volutator (amphipod)	ADT	SG	3.5	11
<403	Charleston Harbor, SC	COA		High species richness (14.9±2.04) SRUs	Benthic species		NE		13
<403	Charleston Harbor, SC	COA		Moderate species richness (9.05±1.33 SRUs	Benthic species		NG		13
<403	Charleston Harbor, SC	COA		Low species richness (5.16) SRUs	Benthic species		NG		13
<403	Charleston Harbor, SC	COA		High species diversity (4.15±0.59) SDUs	Benthic species		NE		13
<403	Charleston Harbor, SC	COA		Moderate species diversity (2.3±0.2) SDUs	Benthic species		NG		13
<403	Charleston Harbor, SC	COA		Low species diversity (1.16) SDUs	Benthic species		NG		13
486±714	Elizabeth River, VA	COA	96-h	Not significantly toxic (4.5±3.24% mortality)	Palaemonetes pugio (grass shrimp)	ADT	NE		12
500	Puget Sound, WA	AETA	15-m	1986 Puget Sound AET	Microtox		*		14
500	Puget Sound, WA	AETA	48-h	1986 Puget Sound AET	Crassostrea gigas (oyster)	LAR	*		14
500				ER-M (50th percentile)					
500	Puget Sound, WA	AETA	15-m	1988 Puget Sound AET	Microtox		*		15
500	Puget Sound, WA	AETA	48-h	1988 Puget Sound AET	Crassostrea gigas (oyster)	LAR	*		15
500	Puget Sound, WA	AETA		1986 Puget Sound AET	Benthic species		*		14
630	Puget Sound, WA	AETA	10-d	1986 Puget Sound AET	Rhepoxynius abronius (amphipod)		*		14
630	Puget Sound, WA	AETA		PSDDA maximum level criteria	Aquatic biota		*		8
654±1049	Commencement Bay, WA	COA	10-d	Highly toxic (78.5±19.5% mortality)	Rhepoxynius abronius (amphipod)	ADT	*		7
679±469	Elizabeth River, VA	COA	96-h	Significantly toxic (50.7±39% mortality)	Palaemonetes pugio (grass shrimp)	ADT	SG		12
680±814	Elizabeth River, VA	COA	96-h	Significant decrease in respiration rates	Palaemonetes pugio (grass shrimp)	ADT	*		12
730	Puget Sound, WA	AETA		1988 Puget Sound AET	Benthic community		*		15
2000	Puget Sound, WA	AETA	10-d	1988 Puget Sound AET	Rhepoxynius abronius (amphipod)	ADT	*		15
3031±4271	Puget Sound, WA	COA	10-d	High prevalence of hepatic lesions (26.7±6.4%)	Parophrys vetulus (English sole)	ADT	*		1
3031±4271	Puget Sound, WA	COA		High prevalence of hepatic idiopathic lesions (88.0±3.7%)	Parophrys vetulus (English sole)	ADT	*		1
3031±4271	Puget Sound, WA	COA		High prevalence of hepatic cellular alterations (44.1±8.5%)	Parophrys vetulus (English sole)	ADT	*		1
5599±24392	Eagle Harbor, WA	COA	10-d	Least toxic (13±7% mortality)	Rhepoxynius abronius (amphipod)	ADT	NE		16
6522±8915	Eagle Harbor, WA	COA	10-d	Moderately toxic (41±9% mortality)	Rhepoxynius abronius (amphipod)	ADT	SG		16
16500	United States	EqPA		Chronic marine EqP threshold	Aquatic biota		*	1	17
39557±48678	Eagle Harbor, WA	COA	10-d	Highly toxic (95.5±8.5 mortality)	Rhepoxynius abronius (amphipod)	ADT	*		16

Concentration: SD = standard deviation

Analysis Type: COA = co-occurrence analysis, AETA = apparent effects threshold approach; EqPA = equilibrium partitioning approach; SQO - sediment quality objective, SQG - sediment quality guideline; SSBA = spiked sediment bioassay approach; SLCA = screening level criteria approach

Test duration: d = day; h = hour; m = minute

Endpoint measured: AET = apparent effects threshold; PSDDA = Puget Sound dredge disposal analysis; LC50 = lethal concentration to 50% of the tested organisms; SRUs - species richness units; SDUs = species diversity units

Life Stage: ADT = adult; LAR = larval; JUV = juvenile

Effects/No effects: NE = no effect; NC = no concordance; SG = small gradient; NG = no gradient; * = effects data used to calculate ERL and ERM values

TOC: total organic carbon (%)

moderately toxic data entry was assigned a "small gradient" descriptor. The average acenaphthene concentration associated with highly toxic samples (78.5±19.5% mortality) was 654 ppb, a factor of 7.6-fold higher than in the least toxic samples. It was assigned an asterisk and used in the calculation of the ERL and ERM values. A total of 30 data entries for acenaphthene were assigned "effects" designators. No biological effects were reported over the range of 1 to 8.8 ppb acenaphthene. The lower 10th percentile value of the effects data (the ERL) was 16 ppb and the median value (the ERM) was 500 ppb. The percent incidence of adverse effects within the minimal-effects, possible-effects, and probable-effects ranges were 20%, 32%, and 84%, respectively.

Phenanthrene data were available from equilibrium-partitioning studies, spiked sediment bioassays, and numerous field surveys performed in many different areas (Table 2). A total of 51 data entries were assigned "effects" designators in the phenanthrene database. Adverse effects were not observed in association with phenanthrene concentrations of <5 ppb to 66 ppb. The ERL value for phenanthrene was 240 ppb and the ERM value was 1500 ppb. The percent incidence of adverse effects within the minimal-effects, possible-effects, and probable-effects ranges were 18%, 46%, and 90%, respectively.

The incidence of adverse **effects increased** with increasing concentrations of all trace metals, **except nickel** (Table 3). The incidence of effects was 10% or less in the minimal-effects ranges and 11 to 47% in the possible-effects ranges for all of the trace metals. The incidence of adverse effects exceeded 75% in the probable-effects ranges for chromium, copper, lead, and silver, but, was only 42.3% and 16.9% for mercury and nickel, respectively. However, the incidence of effects in the probable-effects range for chromium was greatly influenced and exaggerated by data from multiple tests in only two surveys.

The incidence of adverse effects consistently and markedly increased with increasing concentrations of all organic compounds, except p,p'-DDE and total DDT (Table 4). The incidence of effects ranged from 5.0 to 27.3% in the minimal-effects ranges for organic compounds and was 25% or less for all but one of the compounds - fluorene. Within the possible-effects ranges, the incidence of effects ranged from 18 to 75%. The incidence of effects ranged from 50 to 100% in the probable-effects

Table 2. A summary of the available data on the effects of sediment associated phenanthrene (ppb) in coastal sediments.

Concentration (± SD)	Area	Analysis Type	Test Duration	Endpoint Measured	Species	Life Stage	Effects/ No Effects	TOC (%)	Reference
4.6±1.6	Laboratory	SSBA	~4-mo	No significant change in liver somatic indices	Pseudopleuronectes americanus (flounder)	ADT	NE		18
<5	Halifax Harbour, NS	COA	10-d	Not significantly toxic (3% mortality)	Rhepoxynius abronius (amphipod)	ADT	NE		2
<5	Sidney Tar Pond, NS	COA	10-d	Not significantly toxic (3% mortality)	Rhepoxynius abronius (amphipod)	ADT	NE		2
15	Burrard Inlet, BC	SQO		Sediment quality objectives	Aquatic biota		NE		6
<20	Sidney Tar Pond, NS	COA	10-d	Not significantly toxic (4% mortality)	Corophium volutator (amphipod)	ADT	NE		2
39.4±47.6	Laboratory	SSBA	~4-mo	No significant change in kidney MFO induction	Pseudopleuronectes americanus (flounder)	ADT	NE		18
64.6	San Francisco Bay, CA	COA	48-h	Least toxic (23.3±7.3% abnormal)	Bivalve	LAR	NE		4
66.2±57.5	Laboratory	SSBA	~4-mo	No significant change in spleen condition indices	Pseudopleuronectes americanus (flounder)	ADT	NE		18
88	San Francisco Bay, CA	AETA	48-h	San Francisco Bay AET	Oyster, mussel	LAR	*		4
110	United States	EqPA		99% chronic marine criteria	Aquatic organisms		*	1	19
119	Southern California	COA	10-d	Not significantly toxic (23.2% mortality)	Grandidierrella japonica (amphipod)	JUV	NE		3
150	Puget Sound, WA	COA		Low occurrence of hepatic cellular alterations (0%)	Parophrys vetulus (English sole)	ADT	NE		1
150	Puget Sound, WA	COA		Low prevalence of hepatic lesions (0%)	Parophrys vetulus (English sole)	ADT	NE		1
150	Puget Sound, WA	COA		Low prevalence of hepatic idiopathic lesions (32.5%)	Parophrys vetulus (English sole)	ADT	NE		1
159	San Francisco Bay, CA	COA	48-h	Not significantly toxic (31.9±15.5% abnormal)	Bivalve	LAR	NE		4
170	California	AETA	48-h	California AET	Mytilus edulis (bivalve)	LAR	*		5
170	Northern California	AETA		Northern California AET	Benthic species		*		5
180±325	Narragansett Bay, RI	COA	10-d	Not significantly toxic (5.28±3.04% mortality)	Ampelisca abdita (amphipod)	ADT	NE		20
188	San Francisco Bay, CA	COA	10-d	Least toxic (18±6.6% mortality)	Rhepoxynius abronius (amphipod)	ADT	NE		4
199	San Francisco Bay, CA	COA	10-d	Not significantly toxic (18.4±6.8 % mortality)	Rhepoxynius abronius (amphipod)	ADT	NE		4
220	San Francisco Bay, CA	COA	10-d	Significantly toxic (42.9±19.2 % mortality)	Rhepoxynius abronius (amphipod)	ADT	SG		4
222±136	Southern California	COA	10-d	Significantly toxic (51.7% mortality)	Grandidierella japonica (amphipod)	JUV	SG		3
223±169	Burrard Inlet, BC	COA	10-d	Not toxic (4.5±3.02% emergence)	Rhepoxynius abronius (amphipod)	ADT	NE	2.68±2.15	11
223±169	Burrard Inlet, BC	COA	10-d	Not toxic (5.21±3.61% emergence)	Corophium volutator (amphipod)	ADT	NE	3.18±2.1	11
224	San Francisco Bay, CA	COA	48-h	Moderately toxic (59.4±11.3% abnormal)	Bivalve	LAR	*		4
228	San Francisco Bay, CA	COA	10-d	Moderately toxic (33.8±4.7 mortality)	Rhepoxynius abronius (amphipod)	ADT	SG		4
233	San Francisco Bay, CA	COA	48-h	Significantly toxic (55.7±22.7% abnormal)	Bivalve	LAR	SG		4
240	United States	EqPA		95% chronic marine criteria	Aquatic organisms		*	1	19
240				**ER-L (10th Percentile)**					
242	San Francisco Bay, CA	COA	10-d	Highly toxic (67±11.8% mortality)	Rhepoxynius abronius (amphipod)	ADT	SG		4
259	United States	SLCA		NSLC-marine	Benthic spp.		*	1	21
270	California	AETA		California AET values	Benthic species		*		5
270	Southern California	AETA		Southern California AET values	Benthic species		*		5
>290	Southern California	AETA	10-d	Southern California AET values	Rhepoxynius abronius (amphipod)	ADT	—		5
297	Commencement Bay, WA	COA	48-h	Least toxic (15.1±3.1% abnormality)	Oyster	LAR	NE		7
316±582	Elizabeth River, VA	COA	96-h	No significant change in respiration rate	Palaemonetes puglo (grass shrimp)	ADT	NE		12
320	Puget Sound, WA	AETA		PSDDA screening level concentration	Aquatic biota		NE		8
368	United States	SLCA		NSLC-marine	Benthic species		*	1	21
374±461	Elizabeth River, VA	COA	96-h	Not significantly toxic (4.5±3.24% mortality)	Palaemonetes puglo (grass shrimp)	ADT	NE		12
383±332	Laboratory	SSBA	~4-mo	Significant change in liver somatic indices	Pseudopleuronectes americanus (flounder)	ADT	*		18

Table 2 cont.

Concentration (± SD)	Area	Analysis Type	Test Duration	Endpoint Measured	Species	Life Stage	Effects/ No Effects	TOC (%)	Reference
<403	Charleston Harbor, SC	COA		High species richness (14.9±2.04) SRUs	Benthic species		NE		13
<403	Charleston Harbor, SC	COA		Moderate species richness (9.05±1.33) SRUs	Benthic species		NG		13
<403	Charleston Harbor, SC	COA		Low species richness (5.16) SRUs	Benthic species		NG		13
<403	Charleston Harbor, SC	COA		High species diversity (4.15±0.59) SDUs	Benthic species		NE		13
<403	Charleston Harbor, SC	COA		Moderate species diversity (2.3±0.2) SDUs	Benthic species		NG		13
<403	Charleston Harbor, SC	COA		Low species diversity (1.16) SDUs	Benthic species		NG		13
<408±501	Halifax Harbour, NS	COA	10-d	Not significantly toxic (6.8±7.31% mortality)	Rhepoxynius abronius (amphipod)	ADT	NE		2
<408±501	Halifax Harbour, NS	COA	20-d	Not significantly toxic (0.7±1.63% mortality)	Neanthes species (polychaete)	JUV	NE		2
<410±498	Halifax Harbour, NS	COA	10-d	Not significantly toxic (8.5±6.06% mortality)	Corophium volutator (amphipod)	ADT	NE		2
475	San Francisco Bay, CA	COA	48-h	Highly toxic (92.4±4.5% abnormal)	Bivalve	LAR	*		4
478	Commencement Bay, WA	COA	10-d	Least toxic (12.5±4.5% mortality)	Rhepoxynius abronius (amphipod)	ADT	NE		7
487±318	Laboratory	SSBA	~4-mo	Significant increase in kidney MFO induction	Pseudopleuronectes americanus (flounder)	ADT	*		18
510	Northern California	AETA	10-d	Northern California AET	Rhepoxynius abronius (amphipod)	ADT	*		5
510	California	AETA	10-d	California AET	Rhepoxynius abronius (amphipod)	ADT	*		5
510	San Francisco Bay, CA	AETA	10-d	San Francisco Bay AET	Rhepoxynius abronius (amphipod)	ADT	*		4
593	Commencement Bay, WA	COA	48-h	Moderately toxic (23±2.3% abnormality)	Oyster	LAR	*		7
597	Commencement Bay, WA	COA	10-d	Moderately toxic (26±5.2% mortality)	Rhepoxynius abronius (amphipod)	ADT	*		7
670	Laboratory	SSBA	~4-mo	Significant change in spleen condition indices	Pseudopleuronectes americanus (flounder)	ADT	*		18
918±1395	Burrard Inlet, BC	COA	10-d	Not toxic (97.2±2.84% reburial)	Rhepoxynius abronius (amphipod)	ADT	NE	2.8±1.96	11
918±1395	Burrard Inlet, BC	COA	10-d	Not toxic (8.9±2.99% mortality)	Corophium volutator (amphipod)	ADT	NE	2.8±1.96	11
950	Eagle Harbor, WA	COA	4-d	LC50	Rhepoxynius abronius (amphipod)	Juv/ADT	*		9
987±1654	Elizabeth River, VA	COA	96-h	Significant decrease in respiration rates	Palaemonetes puglo (grass shrimp)	ADT	*		12
1000	Puget Sound, WA	SQG		Chemical criteria	Benthic community		*	1	10
1020	United States	EqPA		Interim marine sediment quality criteria (FCV)	Benthic community		NE	1	23
1213±1547	Burrard Inlet, BC	COA	10-d	Not toxic (7.9±5.12% mortality)	Rhepoxynius abronius (amphipod)	ADT	NE	2.64±2.14	11
<1267±2528	Halifax Harbour, NS	COA	20-d	Not significantly toxic (1±2% mortality)	Neanthes species (polychaete)	JUV	NE		2
<1271±2526	Halifax Harbour, NS	COA	10-d	Not significantly toxic (5.2±3.5% mortality)	Corophium volutator (amphipod)	ADT	NE		2
1379±2545	Commencement Bay, WA	COA	48-h	Highly toxic (44.5±19% abnormality)	Oyster	LAR	*		7
1500	Puget Sound, WA	AETA	15-m	1986 Puget Sound AET	Microtox		*		14
1500	Puget Sound, WA	AETA	48-h	1986 Puget Sound AET	Crassostrea gigas (oyster)	LAR	*		14
1500	Puget Sound, WA	AETA	15-m	1988 Puget Sound AET	Microtox		*		15
1500				ER-M (50th percentile)					
1500	Puget Sound, WA	AETA	48-h	1988 Puget Sound AET	Crassostrea gigas (oyster)	LAR	*		15
<1688±2920	Halifax Harbour, NS	COA	10-d	Significantly toxic (61.7±12.5% mortality)	Rhepoxynius abronius (amphipod)	ADT	*		2
1913±2693	Elizabeth River, VA	COA	96-h	Significantly toxic (50.7±39% mortality)	Palaemonetes pugio (grass shrimp)	ADT	*		12
2142	Eagle Harbor, WA	COA	10-d	Moderately toxic (41±9% mortality)	Rhepoxynius abronius (amphipod)	ADT	NC		16
2600	Eagle Harbor, WA	COA	10-d	Least toxic (13±7% mortality)	Rhepoxynius abronius (amphipod)	ADT	NE		16
2838	Commencement Bay, WA	COA	10-d	Highly toxic (78.5±19.5% mortality)	Rhepoxynius abronius (amphipod)	ADT	*		7
3000	Burrard Inlet, BC	COA	10-d	Highly toxic (30.5% emergence)	Rhepoxynius abronius (amphipod)	ADT	*	3.5	11
3000	Burrard Inlet, BC	COA	10-d	Highly toxic (23% emergence)	Corophium volutator (amphipod)	ADT	*	3.5	11
3200	Puget Sound, WA	AETA		PSDDA maximum level criteria	Aquatic biota		*		8

Table 2. cont.

Concentration (± SD)	Area	Analysis Type	Test Duration	Endpoint Measured	Species	Life Stage	Effects/ No Effects	TOC (%)	Reference
3200	Puget Sound, WA	AETA		1988 Puget Sound AET	Benthic species		*		14
3680	Eagle Harbor, WA	COA	4-d	LC50	Rhepoxynius abronius (amphipod)	Juv/ADT	*		9
5400	Puget Sound, WA	AETA	10-d	1986 Puget Sound AET	Rhepoxynius abronius (amphipod)	ADT	*		14
5400	Puget Sound, WA	AETA		1988 Puget Sound AET	Benthic community	ADT	*		15
6900	Puget Sound, WA	AETA	10-d	1988 Puget Sound AET	Rhepoxynius abronius (amphipod)	ADT	*		15
10000	Laboratory	SSBA	10-d	Significant toxicity	Rhepoxynius abronius (amphipod)	ADT	*	0.9	24
11656±14472	Puget Sound, WA	COA		High prevalence of hepatic lesions (26.7±6.4%)	Parophrys vetulus (English sole)	ADT	*		1
11656±14472	Puget Sound, WA	COA		High prevalence of hepatic idiopathic lesions (88.0±3.7%)	Parophrys vetulus (English sole)	ADT	*		1
11656±14472	Puget Sound, WA	COA		High prevalence of hepatic cellular alterations (44.2±8.5%)	Parophrys vetulus (English sole)	ADT	*		1
14000	United States	EqPA		Chronic marine EqP threshold	Aquatic biota		*	1	17
14000	United States	EqPA		EPA acute marine EqP threshold	Aquatic biota		*	1	25
>30000	Labortory	SSBA	14-d	LC50	Grandidierella japonica (amphipod)	ADT	—	0.1	26
>30000	Laboratory	SSBA	14-d	LC50	Grandidierella japonica (amphipod)	ADT	—	1	26
33603	Eagle Harbor, WA	COA	10-d	Highly toxic (95.5±8.5% mortality)	Rhepoxynius abronius (amphipod)	ADT	*		16
<45903±64909	Sidney Tar Pond, NS	COA	20-d	Not significantly toxic (8±5.66% mortality)	Neanthes species (polychaete)	JUV	NE		2
91800	Sidney Tar Pond, NS	COA	10-d	Significantly toxic (100% mortality)	Corophium volutator (amphipod)	ADT	*		2
91800	Sidney Tar Pond, NS	COA	10-d	Significantly toxic (100% mortality)	Rhepoxynius abronius (amphipod)	ADT	*		2
105500	Elizabeth River, VA	COA	28-d	LC50	Leiostomus xanthurus (spot)	JUV	*		27
484000	Sidney Tar Pond, NS	COA	20-d	Significantly toxic (52% mortality)	Neanthes species (polychaete)	JUV	*		2
2363200	Elizabeth River, VA	COA	24-h	LC50	Leiostomus xanthurus (spot)	JUV	*		27
4220000	Elizabeth River, VA	COA	2-h	Highly toxic (100% mortality)	Leiostomus xanthurus (spot)	JUV	*		27

Concentration: SD = standard deviation

Analysis Type: COA = co-occurrence analysis, AETA = apparent effects threshold approach; EqPA = equilibrium partioning approach; SQO - sediment quality objective; SQG = sediment quality guideline; SSBA = spike sediment bioassay approach; SLCA = screening level criteria approach

Test duration: d = day; h = hour; min = minute

Endpoint measured: ER-L = effects range low; ER-M = effects range-median; AET - apparent effects threshold; PSDDA - Puget Sound dredge disposal analysis; organisms; SRUs = species richness units; SDUs = species diversity units; MFO = mixed-function oxidase; FCV = final chronic value; LC50 = lethal concentration to 50% of the tested organisms; EPA = Environmental Protection Agency

Life Stage: ADT = adult; LAR = larval; JUV = juvenile

Effects/no effects: NE = no effect; NC = no concordance; SG = small gradient; NG = no gradient; * = effects data used to calculate ERL and ERM values

TOC: total organic carbon (%)

ranges and equalled or exceeded 75% for all but four compounds. The incidence of effects in the probable-effects range for total PCBs was relatively low (51%).

DISCUSSION

Guidelines Accuracy. Among the trace metals, the most accurate guidelines appeared to be those for copper, lead, and silver; the incidence of effects were very low (<10%) in the minimal-effects ranges, increased steadily through the possible-effects and probable-effects ranges, and were very high (>83%) in the probable-effects ranges. Among the organic compounds, the guidelines appeared to be highly accurate for all of the classes of PAHs and most of the individual PAHs. Except for fluorene and benz(a)anthracene, the incidence of effects was 25% or less at concentrations below the respective ERL values. Except for dibenzo(a,h)anthracene, p,p'-DDE, total DDT, and total PCBs, the incidence of effects was 75% or greater at concentrations that exceeded the respective ERMs. At concentrations in the probable-effects ranges, the incidence of adverse effects was 100% for acenaphthylene, 2-methyl naphthalene, and low molecular weight PAHs and 90% or greater for chromium, lead, silver, benz(a)anthracene, and fluoranthene.

The accuracy of the guidelines for some substances appeared to be relatively low. For example, the incidences of effects associated with nickel were 1.9%, 16.7%, and 16.9%, respectively, in the three concentration ranges. The incidence of effects did not increase appreciably with increasing concentrations of nickel and were very low in all three ranges. The incidence of effects in the probable-effects ranges for mercury and total PCBs were relatively low (42.3% and 51.0%, respectively). Also, the incidence of effects did not increase consistently and markedly with increasing concentrations of p,p'-DDE, and total DDT. The p,p'-DDE and total DDT databases may have been unduly influenced by relatively low equilibrium-partitioning values which were based upon chronic marine water quality criteria intended to protect against bioaccumulation in marine fish and birds, not toxicity to benthic organisms. The incidence of effects in the probable-effects range for chromium ostensibly appeared to be very high, but was unduly exaggerated by data from multiple tests performed in only two studies.

Comparisons with Other Guidelines. Agreement within **a factor of** 3 or less among guidelines developed with different methods has been recommended by a panel of experts as an indication of good precision (Lorenzato et al., 1991). In the following discussion, the comparisons of guidelines were conducted by determining the ratios between them, i.e., the larger of the two values was divided by the smaller value.

The ERL and ERM values reported in Tables 3 and 4 were based upon a considerable expansion and revision of the data base used by Long and Morgan (1990). The quantities of data used to derive the present values exceeded those used previously by factors of 1.4 to 2.6. About 30-50% of the data used in the present analysis came from the data base used previously. Also, the considerable amounts of freshwater data in the previous data base were deleted in the present analysis. Of the 25 ERL values derived in the two analyses, 7 remained unchanged, 9 decreased, and 9 increased. The ratios between the two sets of ERL values ranged from 1.0 to 9.4 (average of 1.88, n=25). The ERL values for only two substances changed by factors greater than 3.0X: arsenic (decreased by 4.2X); acenaphthene (decreased by 9.4X). The ratios between the two sets of ERM values ranged from 1.0 to 7.6 (average of 1.63, n=25). The average ratios between the two sets of ERM values was 1.2 for the individual PAHs and 1.5 for the trace metals; 7 remained unchanged, 7 decreased, and 8 increased. Only one ERM value changed by a factor greater than 3.0: total DDT (decreased by 7.6X). The ERL and ERM values for p,p'-DDE increased by factors of 1.1 and 1.8, respectively. The ERL value for total PAHs remained unchanged and the ERM value increased by a factor of 1.3. The results of these comparisons indicate that the guidelines are relatively insensitive to changes in the data base, once the minimum data requirements have been satisfied.

The National sediment quality criteria proposed by the U.S. Environmental Protection Agency for fluoranthene, acenaphthene, and phenanthrene in salt water are based upon equilibrium-partitioning models (U. S. EPA, 1991a, 1991b, 1991c). The proposed mean criterion for fluoranthene is 1340 ug/g organic carbon (with 95% confidence limits of 620 and 2880 ug/goc). For acenaphthene the mean criterion is 243 ug/goc (with 95% confidence limits of 110 and 520 ug/goc). For phenanthrene the mean criterion is 160 ug/goc (with 95% confidence limits of 74 and **340 ug/goc). Assuming** a TOC concentration of 1%, these criteria values are equivalent to 13400 (6200-28800) ppb dry wt. for fluoranthene; 2430 (1100-5200) ppb dry wt. for acenaphthene; and 1600 (740-3400) ppb dry wt. for phenanthrene The mean criteria exceeded the ERM values of 5100, 500, and 1500 ppb by factors of 2.6,

Table 3. ERL and ERM guideline values for trace metals (ppm, dry wt.) and percent incidence of biological effects in concentration ranges defined by the two values.

	Guidelines		Percent (ratios) incidence of effects*		
Chemical	ERL	ERM	<ERL	ERL - ERM	>ERM
Arsenic	8.2	70	5.0 (2/40)	11.1 (8/73)	63.0 (17/27)
Cadmium	1.2	9.6	6.6 (7/106)	36.6 (32/87)	65.7 (44/67)
Chromium	81	370	2.9 (3/102)	21.1 (15/71)	95.0 (19/20)
Copper	34	270	9.4 (6/64)	29.1 (32/110)	83.7 (36/43)
Lead	46.7	218	8.0 (7/87)	35.8 (29/81)	90.2 (37/41)
Mercury	0.15	0.71	8.3 (4/48)	23.5 (16/68)	42.3 (22/52)
Nickel	20.9	51.6	1.9 (1/54)	16.7 (8/48)	16.9 (10/59)
Silver	1.0	3.7	2.6 (1/39)	32.3 (11/34)	92.8 (13/14)
Zinc	150	410	6.1 (6/99)	47.0 (31/66)	69.8 (37/53)

*Number of data entries within each concentration range in which biological effects were observed divided by the total number of entries within each range.

Table 4. ERL and ERM guideline values for organic compounds (ppb, dry wt.) and percent incidence of biological effects in concentration ranges defined by the two values.

	Guidelines		Percent (ratios) incidence of effects*		
Chemical	ERL	ERM	<ERL	ERL-ERM	>ERM
Acenaphthene	16	500	20.0 (3/15)	32.4 (11/34)	84.2 (16/19)
Acenaphthylene	44	640	14.3 (1/7)	17.9 (5/28)	100 (9/9)
Anthracene	85.3	1100	25.0 (4/16)	44.2 (19/43)	85.2 (23/27)
Fluorene	19	540	27.3 (3/11)	36.5 (19/52)	86.7 (26/30)
2-methyl naphthalene	70	670	12.5 (2/16)	73.3 (11/15)	100 (15/15)
Naphthalene	160	2100	16.0 (4/25)	41.0 (16/39)	88.9 (24/27)
Phenanthrene	240	1500	18.5 (5/27)	46.2 (18/39)	90.3 (28/31)
Low Mol. Wt. PAH	552	3160	13.0 (3/23)	48.1 (13/27)	100 (16/16)
Benz(a)anthracene	261	1600	21.1 (4/19)	43.8 (14/32)	92.6 (25/27)
Benzo(a)pyrene	430	1600	10.3 (3/29)	63.0 (17/27)	80.0 (24/30)
Chrysene	384	2800	19.0 (4/21)	45.0 (18/40)	88.5 (23/26)

Table 4. (continued)

Chemical	Guidelines		Percent (ratios) incidence of effects*		
	ERL	ERM	<ERL	ERL-ERM	>ERM
Dibenzo(a,h)anthracene	63.4	260	11.5 (3/26)	54.5 (12/22)	66.7 (16/24)
Fluoranthene	600	5100	20.6 (7/34)	63.6 (28/44)	92.3 (36/39)
Pyrene	665	2600	17.2 (5/29)	53.1 (17/32)	87.5 (28/32)
High Mol. Wt. PAH	1700	9600	10.5 (2/19)	40.0 (10/25)	81.2 (13/16)
Total PAH	4022	44792	14.3 (3/21)	36.1 (13/36)	85.0 (17/20)
p,p'-DDE	2.2	27	5.0 (1/20)	50.0 (10/20)	50.0 (12/24)
Total DDT	1.58	46.1	20.0 (2/10)	75.0 (12/16)	53.6 (15/28)
Total PCBs	22.7	180	18.5 (5/27)	40.8 (20/49)	51.0 (25/49)

*Number of data entries within each concentration range in which biological effects were observed divided by the total number of entries within each range.

4.9, and 1.1, respectively. The criteria expressed in units of dry wt. would increase with increasing TOC concentrations.

The ERL and ERM values generally agreed within factors of two to three with freshwater effects-based criteria issued by Ontario (Persaud et al., 1992). Lowest Effect Levels and Severe Effect Levels were reported, based upon a screening level concentrations (SLC) approach applied to matching benthic community and sediment chemistry data. The ratios between the present ERL values and the Lowest Effect Levels for Ontario ranged from 1.25 to 3.1 (average of 1.7) for eight trace metals (As, Cd, Cr, Cu, Pb, Hg, Ni, Zn). The ratios between the present ERM values and the Severe Effect Levels for Ontario ranged from 1.0 to 3.4 (average of 2.0) for the same eight trace metals. Of the sixteen comparisons, the ERL/ERM values were lower than the respective values for Ontario in six cases and higher in ten cases.

Among all of these comparisons, most of the guidelines agreed within the recommended factor of 3.0 or less. In the worst case, two values differed by a factor of 9.4.

<u>Merits of the Approach.</u> This approach attempts to identify the concentrations of toxicants that are rarely associated with adverse biological effects and those usually associated with effects, based upon data from many studies. The advantages of this approach are that guidelines can be developed quickly with existing information and that they are based upon data gathered from many different studies. An underlying assumption of the approach is that, if enough data are accumulated, a pattern of increasing incidence of biological effects should emerge with increasing contaminant concentrations.

Data from all available sources were considered in this study, including those from equilibrium-partitioning models, spiked sediment bioassays, and numerous field surveys. The modelling and bioassay methods differ considerably from those used in the field studies, since they generally are performed with single chemicals as if they were acting alone. The field studies invariably involve complex mixtures of contaminants, acting synergistically, additively, or antagonistically. Whereas the modelling studies and spiked sediment bioassays can be used to establish cause-effect relationships for single chemicals, the data from field studies cannot establish such relationships. However, the data from field studies of complex mixtures reflect realworld, natural conditions in ambient sediments. We believe that the most meaningful assessment tools are those that are based upon evidence from and agreement among all three of these methods. If data compiled from different study areas with different pollution histories and physical-chemical properties converge upon ranges of contaminant concentrations that are usually associated with effects, then guidelines derived from those studies should be broadly applicable to many other areas and situations. Therefore, in this report the data from numerous studies were used to identify the concentrations of individual chemicals that were rarely, occasionally, and usually associated with effects.

The biological data compiled for derivation of the guidelines included a variety of different taxonomic groups and toxicological end-points. The sensitivities of the taxa to toxicants may have differed considerably, and, therefore, contributed to variability in the data base. However, we believe that the inclusion of data from multiple taxa ensures the broad applicability of the guidelines and the protection of a diversity of organisms.

The bioavailability of sediment-associated contaminants is controlled to a large degree by certain physical-chemical properties of the sediments. For example, high acid-volatile sulfide (AVS) concentrations appear to reduce the bioavailability of cadmium, and, possibly, other trace metals in sediments (Di Toro et al., 1990). Similarly, the influence of increasing TOC concentrations in reducing the bioavailability of many non-ionic organic compounds has been demonstrated in modelling and laboratory studies (Di Toro et al., 1991; **Swartz et al., 1990**; Pavlou et al., 1987). Significant differences in toxicity can occur at similar toxicant concentrations over relatively small ranges in TOC and/or AVS concentrations (Adams et al., 1992). It has been argued that sediment quality criteria are indefensible if they do not account for factors that control bioavailability (Di Toro et al., 1991). The data evaluated in the present analysis were not normalized to either TOC or AVS concentrations, since only a small minority of the reports that were encountered included results for these parameters. Nevertheless, the present evaluation indicates that the guidelines derived using the approach reported herein are accurate for most chemicals and agree reasonably well with other guidelines. Therefore, they are likely to be reliable tools in sediment quality assessments.

While factors that are thought to control bioavailability were not considered explicity, surely they were operative in the tests of field-collected sediments and influenced the bioavailability of all of the potential toxicants. However, the data that were encountered indicated that TOC concentrations usually ranged from 1 to 3% in most study areas. In contrast, the concentrations of some chemicals differed by several orders of magnitude among the same samples. These observations suggest that, over these large concentration gradients, the relatively small differences in TOC and/or AVS concentrations may have been relatively unimportant in controlling toxicity or, otherwise, were masked in the data analyses.

Since the data bases used to develop the present guidelines included data from many field studies, the guidelines may tend to be more conservative than those based upon only single-chemical approaches. The cumulative (e.g., synergistic) effects of mixtures of toxicants in ambient sediments, including those not quantified, may tend to drive the apparent effective concentrations of individual toxicants downward **(i.e., toward lower concentrations)**.

CONCLUSIONS

Based upon an evaluation of existing data, three ranges in chemical concentrations were determined for 28 chemicals or chemical classes. These ranges were defined by two guideline values: the lower 10th percentile (ERL) and the 50th percentile (ERM) of the effects data distribution. The incidence of biological effects was quantified for each of these ranges as an estimate of the accuracy of the guidelines. The incidence of effects usually was less than 25% at concentrations below the ERL values. For most chemicals, the incidence of effects increased markedly as the concentrations increased. Also, the incidences of effects often were greater than 75% (occasionally 100%) at concentrations that exceeded the ERM values. However, for a few chemicals (especially mercury, nickel, total PCBs, total DDT, and p,p'-DDE) there were relatively weak relationships between their concentrations and the incidence of effects. The guideline values reported herein generally agreed within factors of 3X or less with guidelines derived earlier using the same methods applied to a different data base and with guidelines developed with other methods. The numerical guidelines should be used as informal screening tools in environmental assessments. They are not intended to preclude the use of toxicity tests or other measures of biological effects. The guidelines should be accompanied by the information on the incidence of effects. The percent incidence data may prove useful in estimating the probability of observing similar adverse effects within the defined concentration ranges of particular contaminants.

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DRAFT

Coastal Monitoring & Bioeffects
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6 October, 1993

Dr. David Alexander
Environmental Management
Department of Geology and Geography
University of Massachusetts
Amherst, MA 01003

Dear Dr. Alexander:

Enclosed is the revised version of our manuscript titled "Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments", ms #1433 submitted to Environmental Management.

We have attempted to address all of the comments and suggestions offered by your three reviewers. The comments from Dr. Sowles were particularly helpful and we have addressed all of them. Specifically, we have made the following changes:

- Clarified how we treated the data from different measures of effects.
- Explained that space limitations precluded listing the ascending tables for all of the toxicants. These tables are readily available from the authors.
- Clarified the ambiguous sentence in the Abstract.
- Clarified the TOC conversion factor by moving a sentence from the Discussion to the Methods.
- Speculated on the effects of using merged data and data from individual studies.
- Changed the sentence regarding mercury.
- Explained the rationale for using 10-fold differences as a criterion for including data in the BEDS.
- Included an example in the acenaphthene results of a data evaluation, and, thereby, further defined some of the terms.
- Cleaned up the editorial comments on sentence structure.

However, we could not address the comment on the Corps of Engineers work on contaminated sediments. Since the Corps strongly opposes any numerical standards for sediments, it has not participated in their development. Also, we did not address the comment on a factor of 3 being a barometer of agreement among guidelines from different methods. Since we did not generate this factor, we do not feel the need to defend it. A factor of 3 was the consensus of a panel of experts assembled by the state of California. It was published by California and we simply cited that reference.

Sincerely,

31