Estimating Bioaccumulation Potential in Dredged Sediment Regulation

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The bioaccumulation potential of neutral organic chemicals in dredged sediments is estimated from sediment chemistry. A simple model is used in which concentration data are normalized on sediment organic carbon and organism lipid and a biota/sediment accumulation factor (BSAF) is applied. This presentation describes an experiment comparing predicted with actual measured tissue concentrations of polynuclear aromatic hydrocarbons (PAH) bioaccumulated from sediments by the clam *Macoma nasuta*.

Testing Requirements

Open water disposal of sediments dredged for navigation purposes in the United States is regulated under provisions of section 103 of the Ocean Dumping Act (Marine Protection, Research, and Sanctuaries Act, MPRSA, of 1972) and section 404 of the Clean Water Act (CWA of 1972). Both laws require that the potential for bioaccumulation of toxic chemicals associated with dredged sediments be assessed as part of the regulatory process when such chemicals are suspected or known to be present. The guidance manuals for implementation of the laws use a tiered approach (USEPA/USACE, 1991, 1994). In the first tier, historical data, if it exists, is used to judge whether there is a reason to believe that bioaccumulating chemicals may be present and may be bioavailable to exposed organisms. In the second tier, bioaccumulation potential is estimated from sediment chemistry data. If the potential for bioaccumulation appears to exist, then 28-day laboratory exposures of benthic organisms and analysis of their tissues may follow in the third tier. A fourth tier exists for special situations in which a decision could not be made in any earlier tier.

Theoretical Bioaccumulation Potential

The Tier II sediment screening test is referred to as "Theoretical Bioaccumulation Potential" (TBP) and is based on equilibrium partitioning. TBP is used only for neutral organic chemicals and is simply the application of a BSAF to sediment concentration data in order to estimate the concentration that would result in an organism exposed to the sediment as its only source of contamination. In aquatic systems, neutral organic chemical contaminants such as the PCBs, PAHs, dioxins, etc. primarily partition to the organic carbon of sediments and the lipids of biota. Recognition of this fact led to the convention of normalizing concentrations of neutral chemicals in sediments on the basis of their total organic carbon (TOC) content and similarly normalizing concentrations in biota on the basis of their lipid content. BSAFs are the ratio of the normalized concentrations. Multiplying the TOC-normalized concentration of a neutral chemical in sediment by the BSAF provides an estimation of the steady-state body burden of that chemical in a sediment-exposed organism:

$$TBP = 4(C_s/\%TOC)\%L \quad (1)$$

where C_s = concentration in whole sediment, L = total extractable lipids in an organism of interest, and "4" is the value assigned representing a generalized BSAF for all neutral chemicals and biota.

In theory, the BSAFs for individual neutral chemicals should not differ greatly from one another and can be approximated by a single value. However, the model is a simplification that does not account for differences in bioavailability, the metabolism of compounds, disequilibrium and non-constancy of exposure, organism feeding behavior, or any of the other kinetic or measurement processes that influence bioaccumulation. As such, TBP is protective but not necessarily predictive.

Empirical BSAFs

BSAF data are compiled in a database accessible by modem through an electronic Bulletin Board System at the U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS (The Contaminants BBS, 601-634-4380). Entries include data on organism lipid content, lipid extraction method, organic carbon content of sediment, length of exposure, etc., and the source of the data is given. The data are severely skewed, with most

BSAF values reported as less than 1.0. The frequency distribution of all BSAF entries presently in the database is shown in Figure 1. These data contrast sharply with the universal AF used in the Tier II TBP calculations. The universal BSAF (4) is at the 94th percentile of the database and is about 12-fold greater than the median. Table 1 shows the medians and the interquartile ranges of the BSAFs in the database by group. It can be seen that the medians for the chlorinated groups (PCBs, dioxins/furans, other chemicals) did not differ statistically. However, the median PAH BSAF ranged 16- to 22-fold lower than any of these and is lower than the universal BSAF by a factor of 125. The BSAF data were compiled with the expectation that their use in Tier II dredged sediment bioaccumulation potential calculations would provide more predictive estimations than does the current practice. This assumption was tested using the priority pollutant PAH data of two studies conducted at the Waterways Experiment Station (McFarland et al., 1994a, 1994b; McFarland, 1995).

Field Study

Sediments and their resident infaunal and benthic polychaetes and bivalve mollusks were collected at a location on the continental shelf of the New York Bight Apex. The location had low, but in most cases detectable, concentrations of PAH compounds. Sediment TOC content averaged 0.5 percent in the four samples taken. The biota were pooled by taxonomic group and their tissues analyzed for PAHs and for lipids. Three to five replicates of the seven taxonomic groups were possible, resulting in a total of 24 samples. The sediment and organism PAH data were used to calculate BSAFs for the 15 individual PAHs and for the total of the 15 using "Bootstrap" estimation methods (Manly, 1991).

Laboratory Study

Two sediments were collected in the San Francisco Bay system. One was surficial material from the central Bay (designated "Reference") and the other was from an inner harbor turning basin known to be contaminated (designated "Contaminated"). The total PAH concentration of Reference was about 1.6 µg g^{-1} and that of Contaminated was about 50 µg g^{-1}. TOC contents were similar (0.926 and 1.10 percent). Bentnose clams, *Macoma nasuta*, were collected from a clean area (Tomales Bay, California) and exposed to the sediments in a flow-through facility for 28 days. Exposures were to either bedded sediment or to sediment continuously suspended at about 50 mgL^{-1}. At the end of the exposures the tissues of the clams were analyzed for the 15 priority pollutant PAHs, as in the field study sediments and organisms. Lipids were also measured.

Bioaccumulation potential of the PAH compounds in the San Francisco Bay sediments was estimated using the TBP model and the PAH BSAFs generated by the New York Bight field study. The lipid input data were the mean concentrations of lipids in the Tomales Bay clams at the end of the 28-day exposures in each treatment. The predicted (TBP) PAH concentrations are plotted against the concentrations measured at the end of the 28-day exposures in Figure 2 for the Reference sediment and Figure 3 for the Contaminated sediment. Vertical and horizontal bars and caps are standard errors. The diagonal line represents perfect agreement between predicted and observed concentrations. Observations falling below the line are cases in which measured values exceed predicted. Observations above the line are the reverse. Overestimates and underestimates are nearly equal in the Reference sediment exposures (15 and 17, respectively) and are equal in the Contaminated sediment exposures (16 and 16).

Figure 4 identifies the PAH compounds and shows the distribution of the ratioed means. In the Reference sediment exposures, 56 percent of the predicted concentrations were within a factor of 2 of the measured concentrations. In the Contaminated sediment exposures, 63 percent were within a factor of 2. For the Reference, 72 percent were within a factor of 3 and 75 percent of the Contaminated were within a factor of 3. PAH compounds for which the predicted/measured concentration exceeded or was less than a factor of 3 were acenaphthylene, naphthalene, fluorene, dibenz[a,h]anthracene, and pyrene in the Reference sediment exposures. In Contaminated sediment exposures similar results were observed for acenaphthylene, anthracene, fluorene, and indeno[1,2,3-cd]pyrene. Only for anthracene, fluorene, and naphthalene were statistically significant ($P<0.05$) differences found when t-tests were performed comparing the bootstrap mean TBPs with the mean measured 28-day concentrations.

Although there were individual cases showing large differences between predicted and measured concentrations, Figures 2 through 4 reveal numerous close correspondences. In the case of the total (of the 15) PAH, the effect of averaging over- and underestimations results in very good correspondence. For the totals, the poorest correspondence was 0.76 for the suspended Contaminated sediment exposures, and the closest correspondence was a ratio of 0.97 for total PAH in the suspended Reference sediment exposures.

Acknowledgments

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References

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TABLE 1. DESCRIPTIVE STATISTICS AND COMPARISONS OF GROUPED DATA

Group	n	Median BSAF	25%ile	75%ile	t-test on rankits
All BSAF	689	0.520	0.139	1.453	A*
Invertebrates	608	0.440	0.101	1.120	A
Fish	81	1.600	0.735	2.600	B
Field Studies	492	0.337	0.065	1.525	A
Laboratory Studies	197	0.670	0.428	1.393	C
PCBs	404	0.718	0.230	1.820	C
PAHs	110	0.032	0.006	0.299	D
Dioxins/Furans	129	0.514	0.269	1.275	C
Other Chemicals	46	0.598	0.065	1.800	AC

*Groups with same letter are not significantly different, P < 0.05

FIGURE 1. FREQUENCY DISTRIBUTION OF BIOTA/SEDIMENT ACCUMULATION FACTORS (BSAF) IN CONTAMINANTS BBS DATABASE

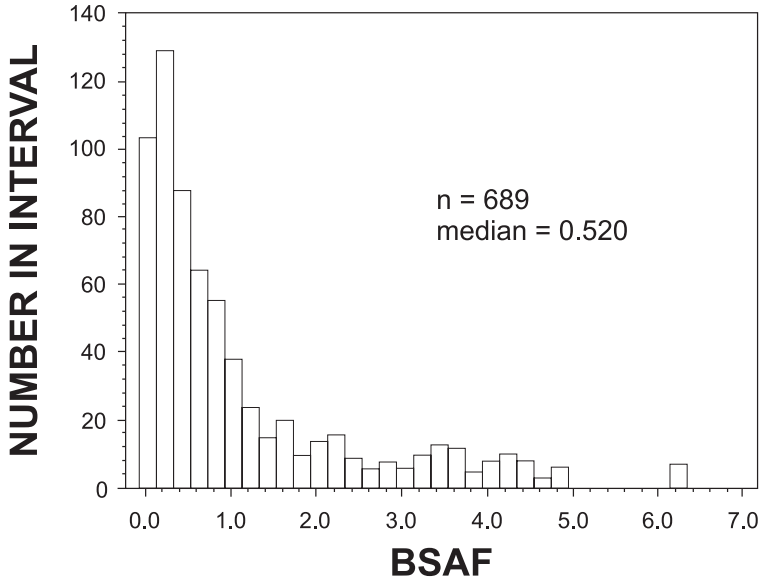


FIGURE 2. TBP-PREDICTED vs MEASURED PAH BIOACCUMULATION IN CLAMS EXPOSED TO REFERENCE SEDIMENT

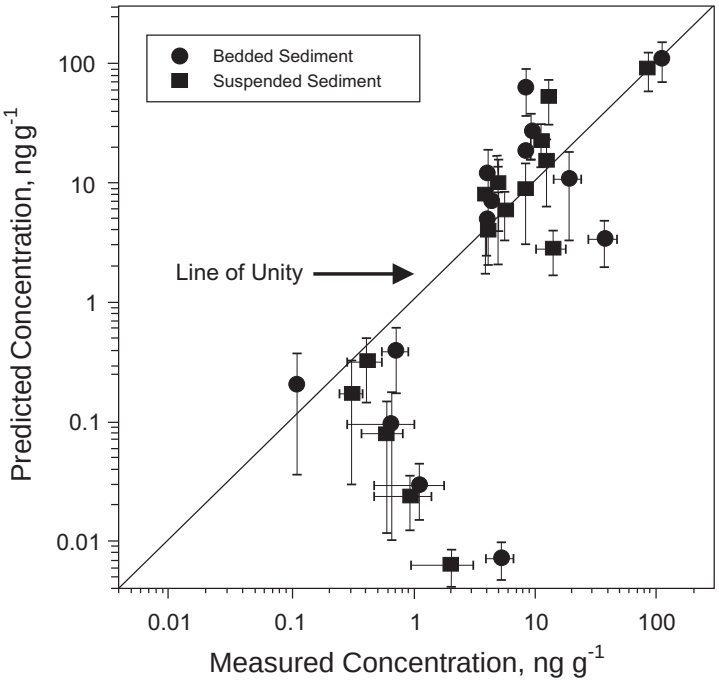


FIGURE 3. TBP-PREDICTED vs MEASURED PAH BIOACCUMULATION IN CLAMS EXPOSED TO CONTAMINATED SEDIMENT

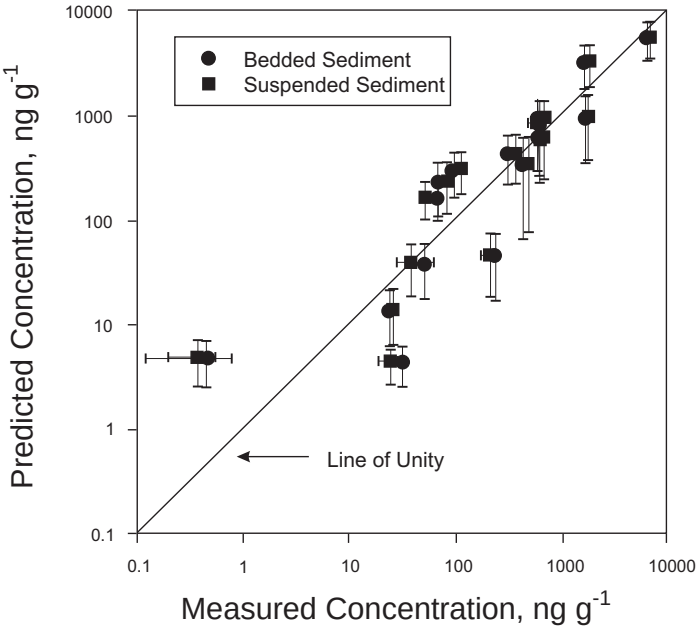
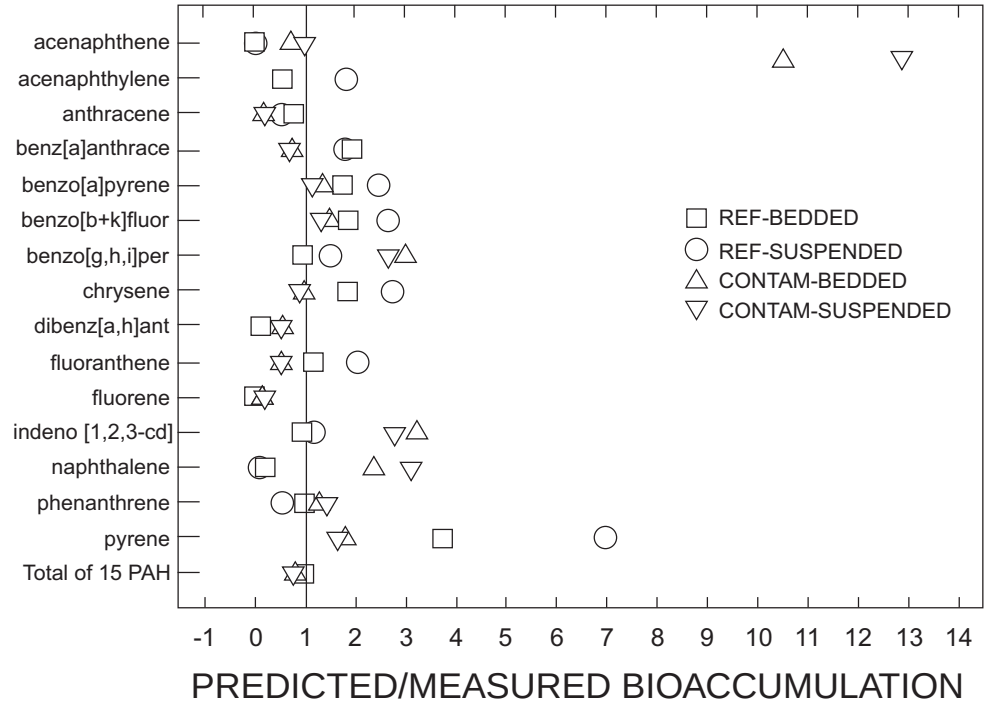


FIGURE 4. AGREEMENT BETWEEN PREDICTED AND MEASURED BIOACCUMULATION: TBP/TISSUE CONCENTRATIONS



ESTIMATING BIOACCUMULATION POTENTIAL IN DREDGED SEDIMENT REGULATION

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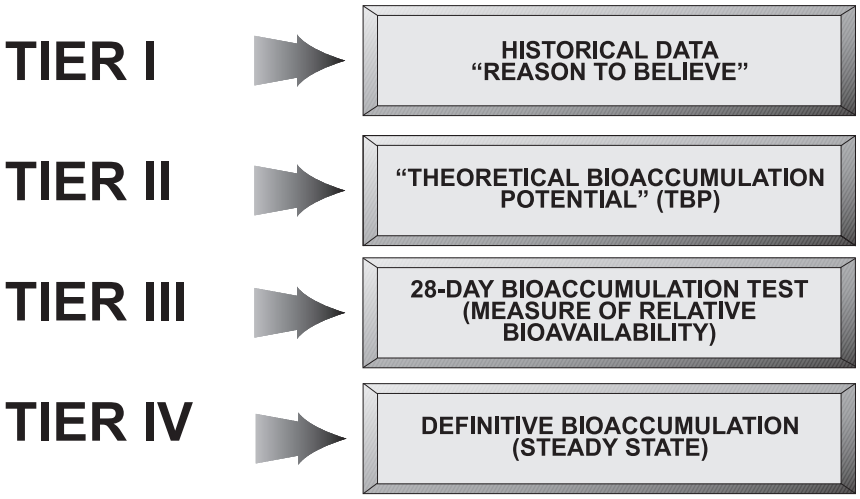
OPEN-WATER DREDGED MATERIAL DISPOSAL IS REGULATED BY:

- **Section 103 of PL-532 of 1972, the Marine Protection, Research and Sanctuaries Act (coastal waters)**
- **Section 404 of PL-530 of 1972, the Clean Water Act (inland and coastal waters)**

THE IMPLEMENTATION MANUALS USE A TIERED-TESTING APPROACH



APPROPRIATE USE OF TBP:

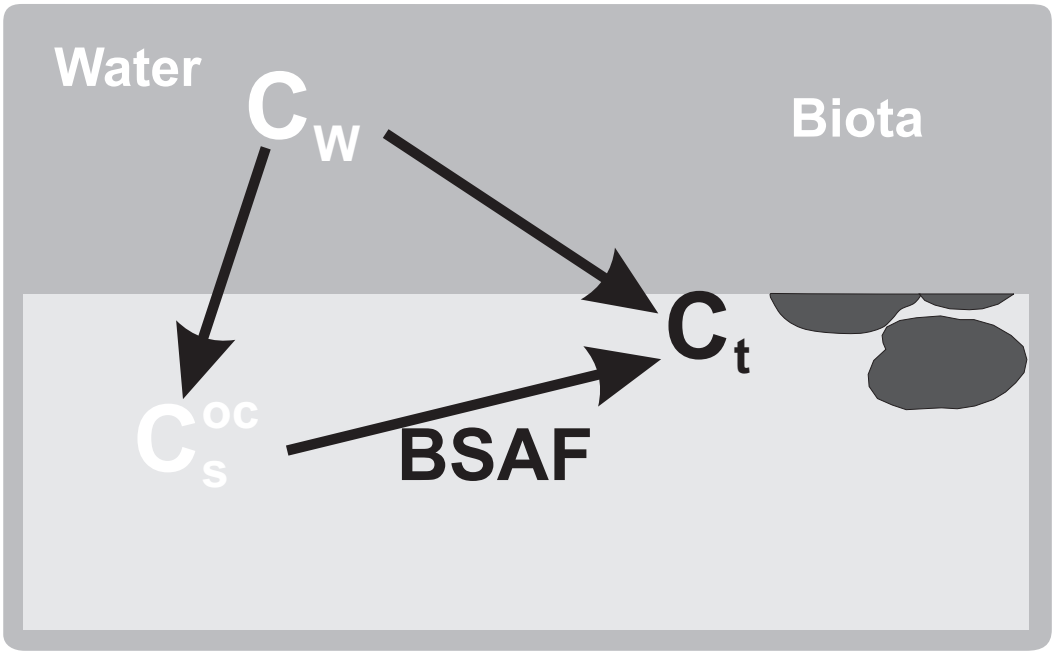
"The TBP calculation in Tier II is applied as a coarse screen to predict the magnitude of bioaccumulation likely to be associated with nonpolar organic contaminants in the dredged material."*

***Draft Inland Testing Manual, June 1994, p. 120.**

TBP:

- Is based on equilibrium partitioning
- Applies only to neutral chemicals
- Uses sediment chemistry data
- Normalizes concentration data on:
  - Organic carbon in sediments
  - Lipid in exposed organisms

EQUILIBRIUM PARTITIONING



SOLUBILITIES OF SOME ORGANIC SOLUTES IN ORGANIC SOLVENTS OR IN WATER, g/mL

	TOLUENE OR BENZENE	OLIVE OIL OR PEANUT OIL	CHLORO-FORM	CARBON TETRA-CHLORIDE	WATER
NAPHTHALENE	0.29	0.13	0.50	0.50	8.80E-7
PHENANTHRENE	0.42	NA	NA	0.42	1.06E-9
LINDANE	0.29	NA	0.24	NA	1.70E-9
DDT	0.78	0.11	NA	0.45	3.10E-12

TBP = 4(Cs/%TOC)%L

TBP = Estimated tissue concentration
4 = An "appropriate" bioaccumulation factor
Cs = Chemical concentration in sediment
TOC = Sediment total organic carbon
L = Organism lipid

- ☆ **The factor, 4, is a universal biota/sediment accumulation factor (BSAF)**

DESCRIPTIVE STATISTICS AND COMPARISONS OF GROUPED DATA

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*Groups with same letter are not significantly different, P < 0.05

TWO STUDIES:

- **East Coast**
- **Field study**
- **Collected benthic infauna and sediments**
- **Analyzed both and calculated BSAFs**

- **West Coast**
- **Lab study**
- **Collected high and low contamination sediments and analyzed**
- **Collected mussels and clams from clean site**
- **Used field study BSAFs to calculate TBPs**
- **Exposed bivalves to the sediments**
- **Compared TBP estimations with actual bioaccumulation**

MEANS COMPARISONS

- Performed t-tests on bootstrap mean TBP and measured mean 28-day tissue concentration for each compound in each treatment
- 5-6 replicates of each treatment
- 1,024 bootstrap iterations for each comparison
- only anthracene, fluorene, and naphthalene were significantly different at $P < 0.05$

CONCLUSION

- For PAH compounds and probably for other neutral organics empirical BSAFs can provide reasonably good estimates of bioaccumulation potential
- Estimates for total PAHs are very good

Next