Benthic Evaluations

Tab L

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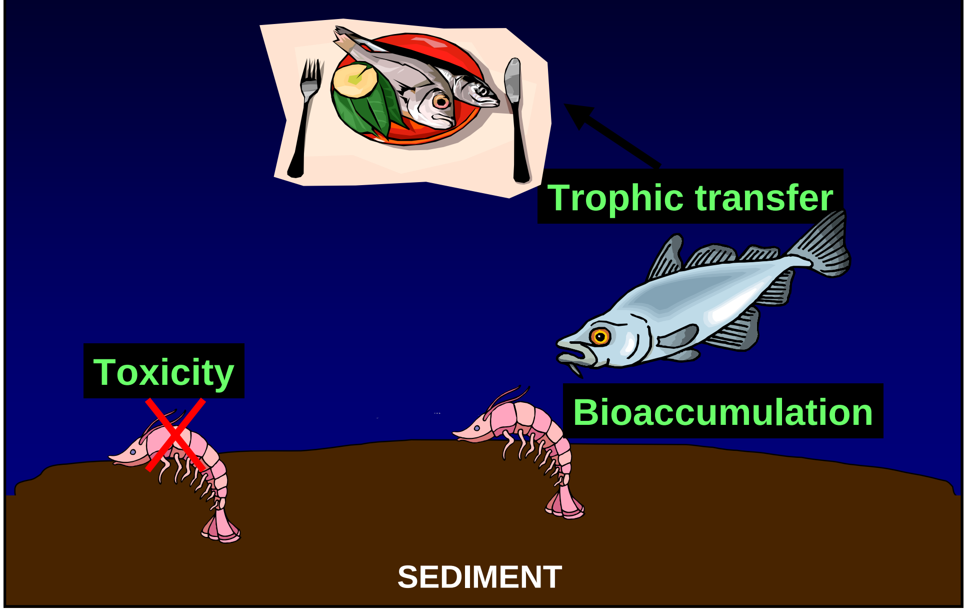
KEY WORDS: Theoretical Bioaccumulation Potential (TBP), Biota Sediment Accumulation Factor (BSAF) Sediment Toxicity and Bioaccumulation Testing

Benthic Evaluations



Benthic Evaluations

Evaluation of potential adverse environmental impact from open water disposal of dredged material

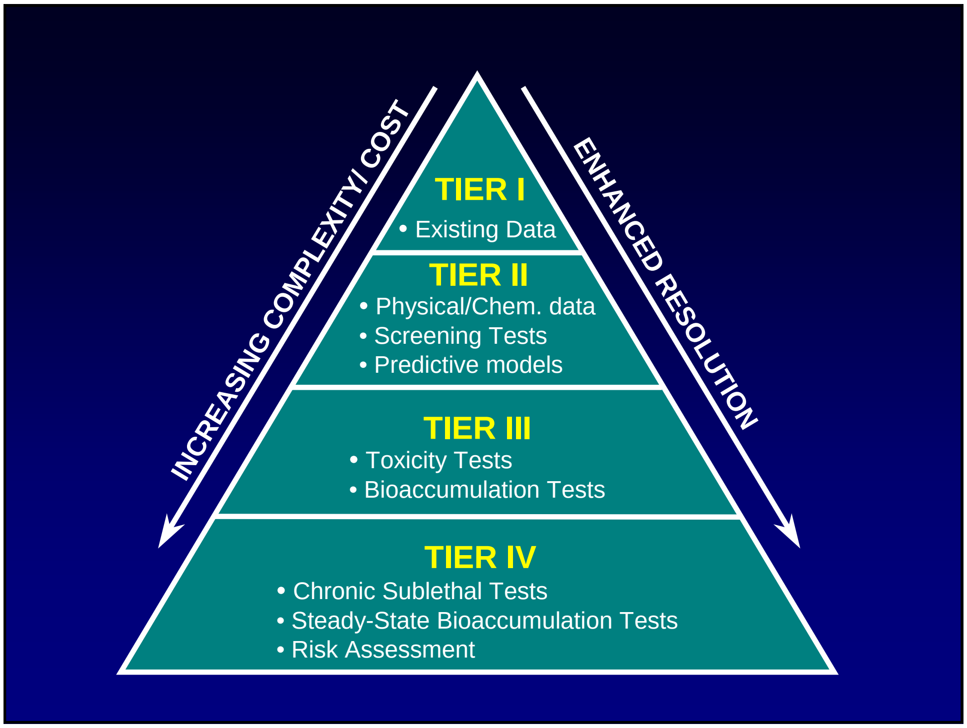
- Potential for direct toxicity to benthic organisms
- Potential for bioaccumulation and movement of contaminants through food chain

Benthic Evaluations

Approach

- Tiered process (I - IV) as far as necessary to make a factual determination

- Factual determination
  – A determination of the potential short-term and long-term effects of a proposed discharge of dredged or fill material on the physical, chemical, and biological components of the aquatic environment.



Benthic Evaluations

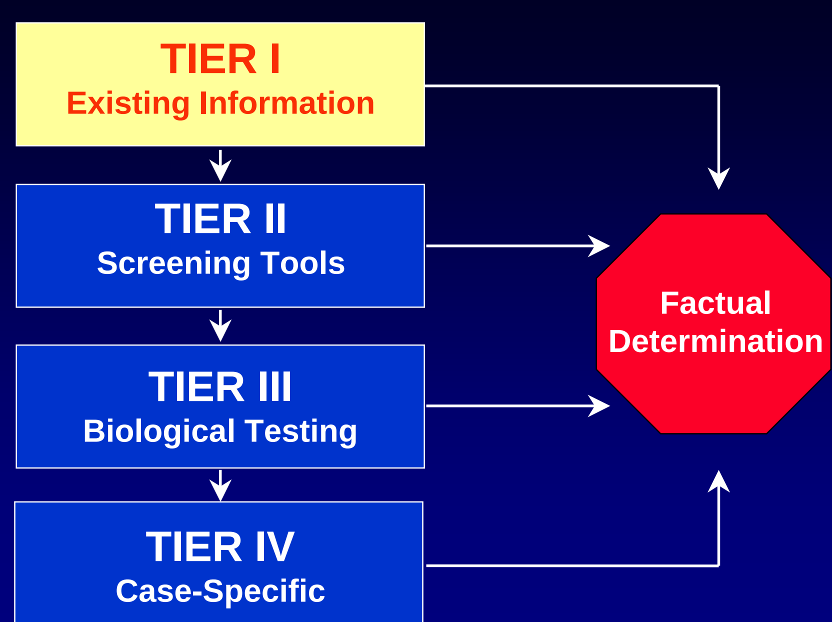
To make a factual determination, the DM is compared to a Reference Sediment

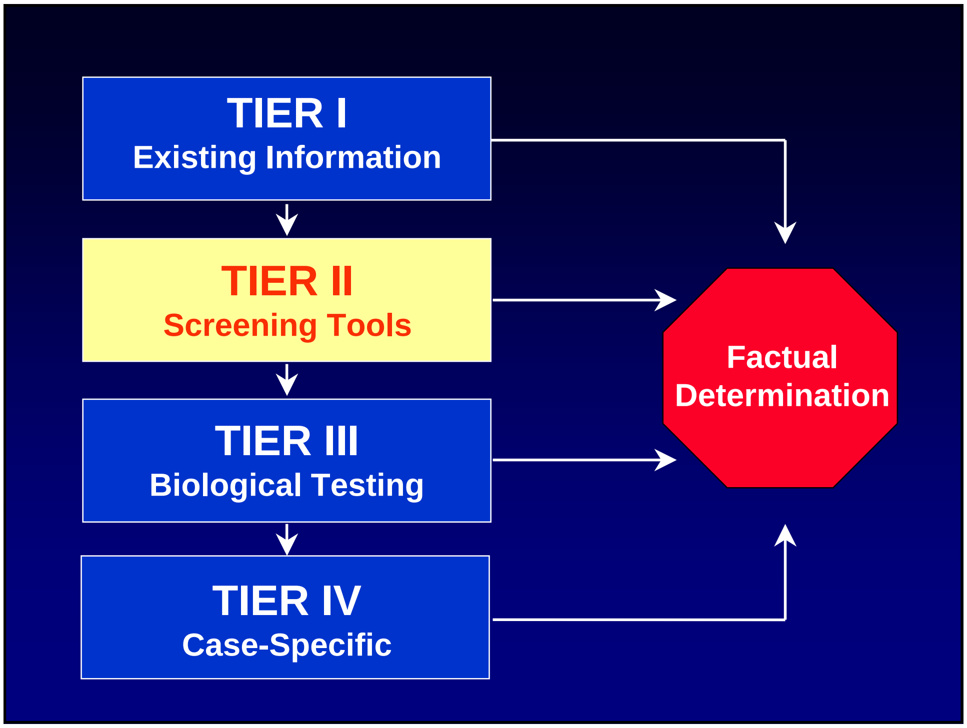
- **Reference sediment provides point of comparison**
- **Comparison is conducted in:**
  - **Tier II, TBP Calculation**
  - **Tier III, Toxicity and Bioaccumulation Assessment**

Benthic Evaluations

Reference Sediment

- Should reflect conditions at disposal site in absence of disposal activity
  (as practicable as possible)
- Characteristics considered
  - Sediment grain size
  - Sediment organic content
  - Relatively free of contaminants





Tier II: Predicting Bioaccumulation

TBP

Theoretical Bioaccumulation Potential

An estimate of the steady-state concentration of non-polar organic chemicals in organisms exposed to contaminated sediment

Tier II:
Predicting Bioaccumulation

TBP is

- A model-derived estimate
- Good only for non-polar (hydrophobic) organics
  - PAHs, PCBs, Dioxins, Chlorinated pesticides
- Used as a screening tool to determine if bioaccumulation testing is warranted

Calculation of TBP

$$\frac{C_t}{\%L} = BSAF \times \frac{C_s}{\%TOC}$$

$$TBP\ (C_t) = \frac{C_s}{\%TOC} \times BSAF \times \%L$$

TBP = C_t = Whole-organism concentration expressed on a wet weight basis in the same units of concentration as C_s

C_s = conc. in sediment (any units)

%L = lipid content of organism (percent of total wet weight)

%TOC = total organic carbon content of sediment (percent of dry weight)

BSAF = biota/sediment accumulation factor

BSAF: Theoretical VS Empirical Values

Theoretical BSAFs:

- Values of 1.7 and 4 have been proposed
- Factors not accounted for:

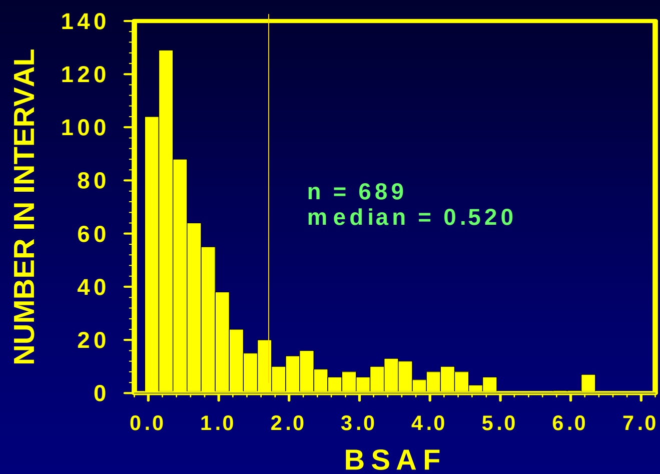
  bioavailability, metabolism, feeding behavior, etc.
- Likely protective, but not predictive

Empirical BSAFs:

- Derived from laboratory exposed or field-collected organisms
- May not represent steady-state values
- Accuracy depends on the quality of analytical chemistry

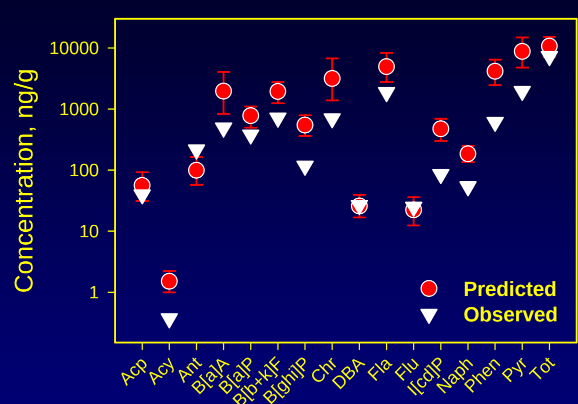
BSAF database
http://el.erdc.usace.army.mil/bsaf

Empirical BSAF values



Compilation from BSAF database (V. McFarland, 1996)
http://el.erdc.usace.army.mil/bsaf

TBP vs Measured Bioaccumulation



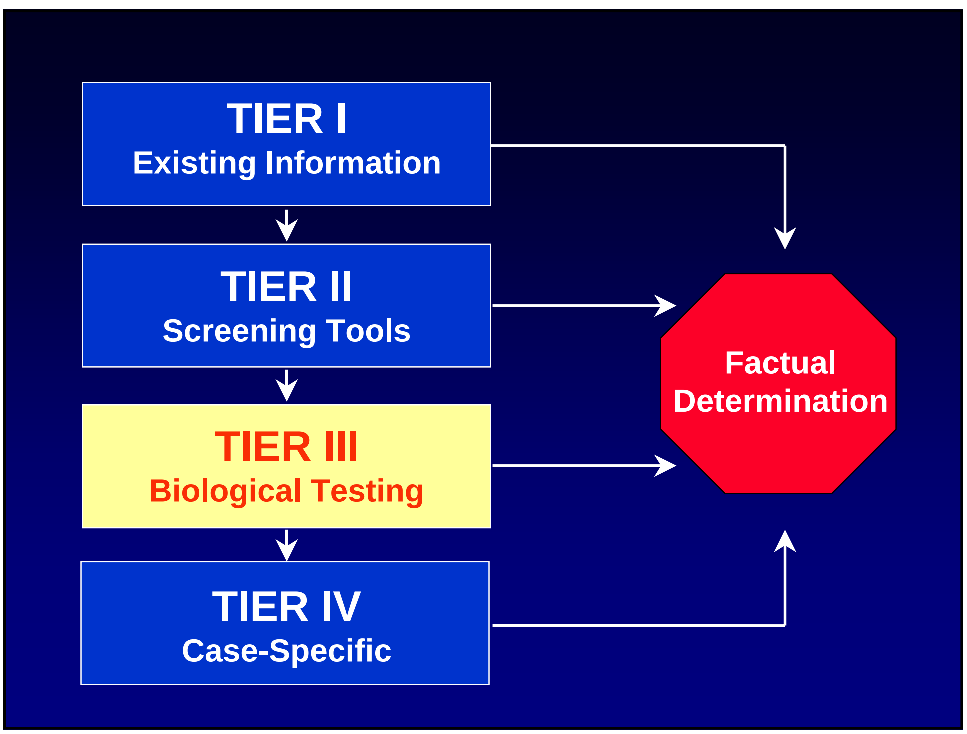
Uncertainty Calculation

Clarke, J. U. and V. A. McFarland. (2000). "Uncertainty Analysis for an Equilibrium Partitioning-Based Estimator of Polynuclear Aromatic Hydrocarbon Bioaccumulation Potential in Sediments," *Environmental Toxicology and Chemistry* 19, 360-367

Tier II: Predicting Bioaccumulation

Statistically compare TBP in DM and REF

- Bioaccumulation not predicted (DM < REF)
  - –Proceed to Tier III
  - –Toxicity testing is required
- Bioaccumulation predicted (DM > REF)
  - –Proceed to Tier III
  - –Toxicity <u>and</u> bioaccumulation testing is required
  - –Seek other disposal alternatives
  - –Abandon project



Tier III: Biological Testing

1. Evaluate **toxicity** of DM to benthic organisms
2. Evaluate **bioaccumulation** of contaminants in benthic organisms exposed to DM

Tier III: Biological Testing

Benthic Toxicity Test

- Conduct whole-sediment toxicity tests
  Porewater tests not acceptable
- Compare DM to reference and control sediments
- Survival of organisms as toxicological endpoint

Tier III: Toxicity Test

Test Design

- Short-term exposure (typically 10 days)
- Measure survival
- At least two species of organisms tested
- No feeding (in most cases)
- Minimum 5 replicates/ treatment
- Test validity based on >90% survival in control sediment

Tier III: Toxicity Test

Toxicity Test Species

- Species representing three life history strategies (burrowing organism, deposit feeder, and filter feeder)
- If only two different species are used, they should together cover the three life history strategies

Tier III: Toxicity Test

Selection of Toxicity Test Species

Other factors to consider:

- **High responsiveness to contaminants**
- **Low responsiveness to non-contaminant effects (e.g., grain size)**
- **Standardized protocol**
- **Ecologically relevant (e.g., infaunal)**
- **Availability (e.g, amenable to culturing)**

Required to utilize at least one benchmark species

Candidate Toxicity Test Species

Marine/Estuarine

Amphipods

Leptocheirus plumulosus*

Ampelisca abdita*

Eohaustorius estuarius*

Rhepoxynius estuarius*

* = Benchmark species

Candidate Toxicity Test Species

Marine/Estuarine

Polychaetes

*Neanthes arenaceodentata**

Nereis virens

* = Benchmark species

Candidate Toxicity Test Species

Marine/Estuarine

Other Invertebrates

Mysid shrimp

Americamysis sp.

Clams

Panaope generosa

Harpacticoid copepods

Amphiascus tenuiremis

Grass shrimp

Palaemonetes sp.

Candidate Toxicity Test Species

Freshwater

Amphipods

Hyalella azteca*

Midges

Chironomus tentans*
Chironomus riparius*

Oligochaetes

Tubifex tubifex

Mayfly

Hexagenia limbata

* = Benchmark species

Commonly Used Test Species

Marine/Estuarine

Species	Group	Users
Ampelisca abdita	Amphipod	Many
Leptocheirus plumulosus	Amphipod	Many
Euhastorius estuarius	Amphipod	Many
Rhepoxinius abronius	Amphipod	Many
Neanthes arenaceodentata	Polychaete	Few
Panope generosa	Clam	Few
Nereis virens	Polychaete	Few
Palaemonetes sp.	Grass shrimp	Few
Grandidierela japonia	Amphipod	Few

Commonly Used Test Species

Freshwater

Species	Group	Users
Hyalella azteca	Amphipod	Many
Chironomus tentans or *C. riparius*	Midge	Many
Hexagenia limbata	Mayfly	Few
Lumbriculus variegatus	Oligochaete worm	Few
Tubifex tubifex	Oligochaete worm	Few

Tier III: Toxicity Test

Potential Non-Contaminant Factors

- **Sediment grain size**
- **Salinity**
- **Ammonia / Sulfide toxicity**
- **Nutrition**

Tier III: Toxicity Test

Toxicity Test Evaluation

- Mortality in dredged material is 10% greater than reference (20% for amphipods), and
- Statistically different from reference?

If No, material is not predicted to be toxic

If Yes, material is predicted to be toxic

Benthic Toxicity Tests

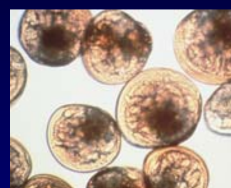
Issues and Concerns

- Near-bottom invertebrates, such as mysids, may not be adequately exposed to sediment. They were much less responsive to contaminated sediments than burrowing amphipods in a comparative study.
- Higher responsiveness of chronic *Leptocheirus* test (lethal and sublethal endpoints) is uncertain.
- Few non-amphipod chronic/sublethal whole sediment tests are available and their relative responsiveness is uncertain.

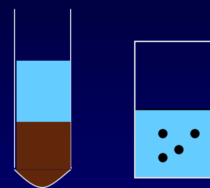
Stay away from porewater tests!

Bad because they lack realism

Use pelagic test organisms



Exclude solid phase

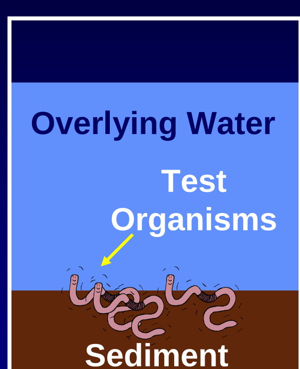


Good because

- Quick screening of samples
- Useful for toxicity identification evaluation
- Excludes effects caused by grain size

Tier III: Biological Testing

Benthic Bioaccumulation Test



- Conduct whole-sediment bioaccumulation tests
- Compare DM to reference and control sediments
- Accumulation of chemicals of interest in organisms as endpoint

Tier III: Bioaccumulation Test

Test Design

- 28-day exposure
- No feeding
- Minimum 3 replicates/treatment
- Measure tissue concentration at conclusion of exposure
- Must have 2 different species

Selection of Bioaccumulation Test Species

Desirable characteristics:

- Sediment ingester
- Infaunal
- Tolerant of contamination
- Adequate biomass
- Inefficient metabolizers
- Easily collected or cultured

Candidate Bioaccumulation Test Species

Marine/Estuarine

Clams

Macoma nasuta *

Mercenaria mercenaria

Yoldia limatula

Polychaetes

Nereis virens *

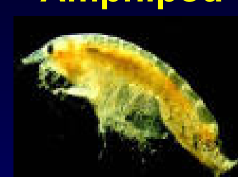
Neanthes arenaceodentata *

* = Benchmark species

Candidate Bioaccumulation Test Species

Freshwater

Amphipod



Diporeia sp.

Oligochaete

Lumbriculus variegatus *

Mayfly

Hexagenia limbata

Clam

Corbicula sp.

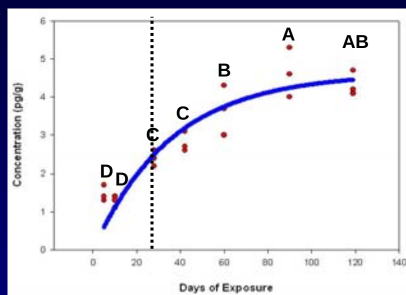
* = Benchmark species

Exposure duration

Is steady-state bioaccumulation reached in 28 days?

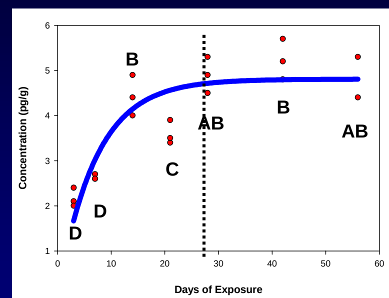
2,3,7,8 TCDF

Macoma nasuta



Time to Steady State = 108 days

Nereis virens



Time to Steady State = 21 days

DDT Bioaccumulation – Time to Steady State

TSS_{95} = Time for 95% steady-state $(2.99/K_e)$

Organism	TSS_{95} (days)
Leptocheirus (amphipod, adults)	6
Leptocheirus (amphipod, juveniles)	2
Hyalella (amphipod, juveniles)	7
Neanthes (polychaete, males)	10
Neanthes (polychaete, females)	41
Nereis (polychaete, adults)	85
Macoma (bivalve, adults)	108

Biotransformation

Metabolism/bioaccumulation of B*a*P in benthic invertebrates *Environ. Toxicol. Chem.* 23, 2004 2589

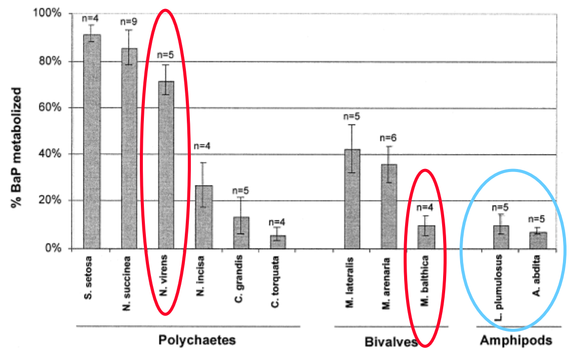


Fig. 1. Percent of benzo[*a*]pyrene (B[*a*]P) body burden metabolized by benthic invertebrates after 7 d of exposure to contaminated sediment (error bars = 95% confidence interval, *n* = sample size). *Nereis succinea* data represent the mean of all values from experiments 1 and 2.

Nereis **is a very efficient metabolizer of PAHs but amphipods used in toxicity tests are not!**

Tier III: Bioaccumulation Test

Conclusion of Exposure

- **Collect all remaining/surviving organisms from exposure chambers**
- **Allow organisms to purge gut content**
- **Conduct chemical analysis of tissues**

Evaluation of Bioaccumulation Data

Concentration of contaminant in organism exposed to dredged material exceed FDA action levels?

If Yes, bioaccumulation is predicted to be adverse

If No, Is concentration of contaminant in organism exposed to dredged material greater than reference?

Evaluation of Bioaccumulation Data

FDA Action Levels (8/2000)[1] for edible portion of fish

Methylmercury	1.0 ppm
Chlordane	0.3 ppm
Chlordecone	0.3 ppm
DDT + DDE	5 ppm
Dieldrin + Aldrin	0.3 ppm
Heptachlor + Heptachlor Epoxide	0.3 ppm
Mirex	0.1 ppm

[1] Updates obtained by contacting FDA, Center for Food Safety and Applied Nutrition, HFF-326, 200 C Street, S.W., Washington, D.C. 10204; 202-205-5251 http://vm.cfsan.fda.gov/~lrd/fdaact.html

Evaluation of Bioaccumulation Data

Concentration of contaminant in organism exposed to dredged material greater than reference?

If Yes, consider

- Number of species tested
- Number of contaminants > reference
- Magnitude of bioaccumulation
- Toxicological importance
- Biomagnification potential
- Comparison to background
- Compare with critical body residues (CBRs)

If No, bioaccumulation is not predicted to be adverse

Benthic Bioaccumulation Tests

Issues and Concerns

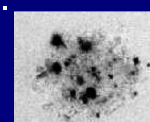
- Recently developed micro-method for extraction and analysis requires smaller tissue mass.
- Test species with high biotransformation ability, such as *Nereis virens*, not suitable for assessing bioaccumulation of PAHs.
- For high k_{ow} compounds, time for steady state typically longer than 28 days for large invertebrates (e.g. *Macoma*), but typically shorter in small invertebrates.
- Studies should conducted to determine whether *Leptocheirus* and *Ampelisca* are adequate bioaccumulation test species.

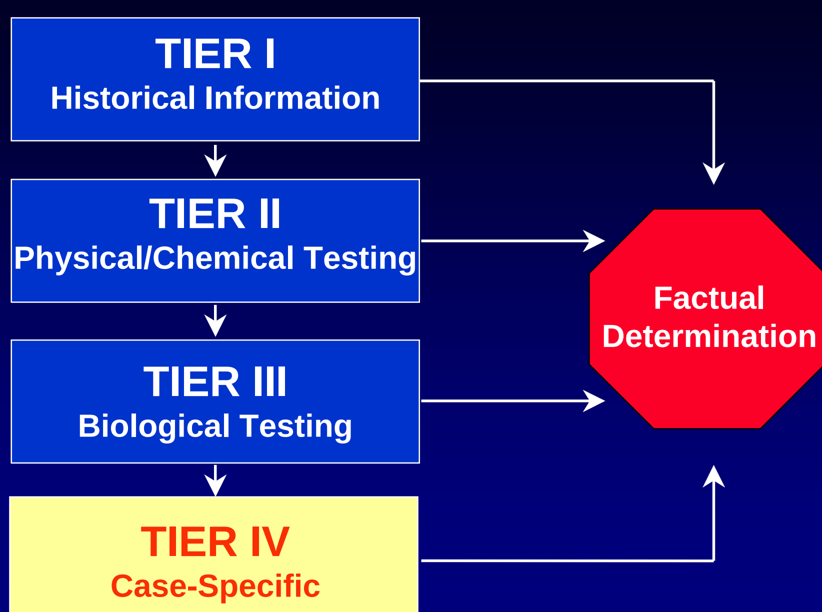
Benthic Bioaccumulation Tests

Issues and Concerns

Bioaccumulation data for heavy metals is difficult to interpret

- Bioavailability complex, influenced by different processes (binding to acid-volatile sulfide and organic carbon, complexation by ligands, oxidation).
- Essential (Fe, Cu, Zn) vs non-essential metals (Hg, Pb, Cd, U).
- High potential for detoxification (metallothioneins, granules).
- Extremely diverse mechanisms of toxicity.
- Concentration at site of toxic action not necessarily related to whole-body accumulation due to sequestration mechanism, therefore, difficult to predict effects from whole-body concentration.





Tier IV: Case-Specific Studies

- Chronic sublethal tests
- Steady-state bioaccumulation
- Risk assessment

Benthic Evaluations

Conclusions

- Evaluate for potential of DM to cause adverse effects on benthic organisms
- Evaluate for potential of DM to contain contaminants that can bioaccumulate to concentrations at which adverse effects to environment can potentially occur
- Follow tiered process only as far as necessary to make a factual determination