Bioaccumulation Evaluations

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Benthic Bioaccumulation Evaluation

• Used to estimate potential for adverse effects through trophic transfer of contaminants

• One line of evidence to support decision concerning suitability for open water disposal
Conceptual Model

Dredged Material Placed in Open Water

Pathways

Receptors

Short Term Turbidity

Long-Term Exposure

Water Column

Direct Contact

Bio-accumulation

Dredged Material Assessment and Management Seminar
24-26 May 2011, Jacksonville, FL
Bioaccumulation Evaluation

Increasing information and cost

Tiered process → follow as far as necessary to make decision

- TIER 1: Evaluation of existing data
- TIER 2: Chemistry, screening, and models
- TIER 3: Toxicity and bioaccumulation bioassays
- TIER 4: Site or region-specific analysis

Information adequate for risk-based decision (STOP)
Bioavailability and Bioaccumulation: Definitions

Benthic organisms are not exposed to $C_{\text{sediment}}$ or $C_{\text{total}}$. Only “bioavailable” chemicals can be taken up.

**Bioavailability** describes the phenomenon that not the total compartment concentration is available for uptake by organisms, but only a specific *fraction*

- **Bioavailable**: Portion of the total quantity or concentration of a chemical in the environment that is potentially available for uptake by organisms.
- **Uptake**: Movement of a contaminant into an organism.
- **Biotransformation**: Chemical alterations of a compound occurring within the organism.
- **Elimination**: Movement of a contaminant out of an organism.
- **Bioaccumulation**: Net uptake of a chemical from all sources following exposure over a exposure period.
Tier II: Predicting Bioaccumulation

Thermodynamically-based
Theoretical Bioaccumulation Potential (TBP)

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

• Used as a coarse screening tool to determine if bioaccumulation testing is warranted

• Compare TBP for Reference and DM

• Only works for non-polar (hydrophobic) organics
  ➢ PAHs, PCBs, Chlorinated pesticides
Tier II: Predicting Bioaccumulation

\[
TBP = \text{BSAF} \times \frac{C_s}{\%\text{TOC}} \times \%L
\]

- **BSAF** = biota/sediment accumulation factor
- **\(C_s\)** = conc. in sediment (any units)
- **\%TOC** = total organic carbon content of sediment
- **\%L** = lipid content of organism

**BSAF** = \(\frac{C_{org}}{C_s}\) (lipid normalized)

(organic carbon normalized)
BSAF Database - http://el.erdc.usace.army.mil/bsaf
Tier III: Bioaccumulation Test

- Conduct whole-sediment bioaccumulation tests
- Compare DM to reference
- Accumulation of chemicals of interest in organisms as endpoint
Tier III: Bioaccumulation Test

Test Design

- Time zero tissue analysis
- 28-day exposure
- No feeding
- Minimum 3 replicates/treatment
- Measure tissue concentration at conclusion of exposure
Selection of Test Species

Desirable characteristics

- Sediment ingester
- Infaunal
- Tolerant of contamination
- Easily collected or cultured
- Inefficient metabolizer (PAHs)
- Adequate biomass

• 2 species should / must be used (CWA / MPRSA)
Bioaccumulation Test Species
Freshwater

Oligochaete

Lumbriculus variegatus

Asian Clam

Corbicula fluminea
Bioaccumulation Test Species

Marine / Estuarine

Macoma nasuta

Mercenaria mercenaria

Yoldia limatula

Nereis virens

Neanthes arenaceodentata

Arenicola marina
Exposure duration

- **Steady State** – final stable concentration of a contaminant in tissue under constant exposure conditions

- **SS** will not always be reached in 28-d depending on:
  - contaminant hydrophobicity
  - species ability to biotransform and eliminate contaminants

### Example: 2,3,7,8 TCDF

<table>
<thead>
<tr>
<th>Species</th>
<th>SS (d)</th>
</tr>
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<tbody>
<tr>
<td>Macoma nasuta</td>
<td>108</td>
</tr>
<tr>
<td>Nereis virens</td>
<td>21</td>
</tr>
</tbody>
</table>

**Graphs:**

- **Macoma nasuta**: SS = 108 d
- **Nereis virens**: SS = 21 d
Exposure duration

Exposures up to 56 d to New York harbor sediments and kinetic method to determine fraction of SS at 28-d

- 28-d exposure adequate for *Nereis virens* but longer exposure required for *Macoma nasuta*

- Site-specific determinations of SS can be made in Tier IV or correction factors may be applied

- Correction factor of 2 or less appears appropriate for most compounds and species
Time to Steady-state Bioaccumulation

While over 90 days are necessary for DDT to approach steady-state in *Macoma nasuta*,

toxicokinetics modeling predicts steady-state body residues of DDT in 6 days in *Leptocheirus plumulosus*

- Microscale analytical methods were developed and are routinely used at ERDC
- Small mass requirement (e.g., 100 mg) while maintaining adequate method sensitivity
- 25-30 amphipods exposed in 200 g of sediment generate enough tissue for PCB congeners analysis
Comparative Bioaccumulation

• *Leptocheirus* BSAF values for PCBs were higher than those for *Macoma*, substantially so for high congeners.

• More conservative surrogate for benthic bioaccumulation.

• Uptake from ingestion of fine sediment likely more relevant pathway for *Leptocheirus*, contributes to higher BSAFs.

• *Leptocheirus* under evaluation for routine use in bioaccumulation evaluation.
Conclusion of Exposure

- Collect all remaining/surviving organisms from exposure chambers
- Allow organisms to purge gut content or excise gut
- Conduct chemical analysis of tissues
Interpreting Bioaccumulation Data

- Statistical comparison to FDA action levels or state fish advisories
- Statistical comparison of bioaccumulation in DM vs. Reference Material
- Assess toxicological relevance and magnitude
- Compare to background
- Compare residue to effect values
- Evaluate propensity to biomagnify
- Evaluate potential to impact higher trophic levels
Food Web / Trophic Transfer

- When biomagnification suspected, higher-trophic level receptors include d in the evaluation

- Trophic Transfer Models
  - Use bioaccumulation test data to estimate residue in higher trophic levels

- Use site-specific information

“all models are wrong and some are useful”
Executable program to calculate, with inputs provided by users, potential human health and ecological risks due to bioaccumulation.

Fish concentrations estimated via a food web model (hydrophobic compounds) or trophic transfer factors (metals).

\[
C_f = \frac{k_1 * C_{wd} + k_d * C_{diet}}{k_2 + k_e + k_m + k_g}
\]
Food Web Model: TrophicTrace

- Calculate risks to ecological receptors (e.g., fish, osprey, bald eagle, mink, and otter) evaluated by comparing to toxicity reference values (TRVs)

- Potential human health effects are evaluated through Reference Doses for noncarcinogenic outcomes and Cancer Slope Factors for carcinogenic outcomes


Interpretation of Tissue Residue

• **Environmental Residue Effects Database**
  - Web-based resource
  - > 15,000 records for >400 chemicals
  - Lethal and sublethal endpoints
  - Includes data from 2,400 studies
  - Updated regularly

![Environmental Residue Effects Database](http://el.erdc.usace.army.mil/ered/)

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Literature: (lowest effect value)
No-effect: 300 µg/kg clam
Lowest-effect: 1,530 µg/kg worm

ERED found at: [http://el.erdc.usace.army.mil/ered/](http://el.erdc.usace.army.mil/ered/)
Interpretation of Tissue Residue

Species Sensitivity Distribution (SSD)

- Distribution of literature data reporting effect associated with tissue concentration
- Use the SSD to select the level of species protection and degree of conservatism


Interpretation of Metals

• Potential for trophic transfer
  - Only metal in certain compartments is biologically available
  - High metal distribution in the prey and potential for detoxification (metallothioneins, granules)

• Critical body residues
  - Essential (Fe, Cu, Zn) vs. non-essential metals (Hg, Pb, Cd, U)
  - 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 Evaluation

Steady State Bioaccumulation

• e.g., extended sediment exposure; derivation of site specific kinetics

Detailed Evaluation of Impact to Higher Trophic Levels

• e.g., ecological and human health risk assessment
Conclusions

• Evaluation of bioaccumulation, typically using laboratory sediment exposure, provides information for assessing long-term effects to higher trophic-level receptors.

• As a line of evidence, bioaccumulations should be used along with other ones (e.g., direct toxicity) in a weight of evidence approach to determine risk.

• Evaluation complexity ranges widely from simple modeling to full risk assessment. Increase complexity as necessary to reach a conclusion.
Direct Measurement of Bioaccumulation

- Allows for site-specific determinations
- Site species may be used
- Standardized and validated approach

Problems
- Traditional approaches use lengthy and costly bioaccumulation laboratory exposures.
- Variability across species (e.g., time to steady-state, routes of uptake, metabolism) hampers extrapolation
- Health of test organisms
- Organism availability and challenging biomass requirement for chemistry
Passive Samplers for Use in Sediment

Passive sampler accumulates freely-dissolved organic contaminants from surrounding water into a solid phase (e.g., polymer). Technique based on simple equilibration between porewater and sorbent phase.

Use cost-effective approaches for estimating porewater concentration and predicting bioaccumulation.

PDMS (or SPME)  Polydimethylsiloxane fiber
PED          polyethylene
POM          Polyoxymethylene
Passive Sampler Assessment of Bioaccumulation

Non-depletive extractions (partition based / biomimetic) that measure freely dissolved concentrations with passive samplers:
Measuring what is “actually available”

1. ‘Calculation’ approach (indirect; $K_{\text{sampler}}$, BCF needed)
2. ‘Comparison’ approach (direct)
PW-estimated and Directly-measured Bioaccumulation

Passive sampler and benthic invertebrate co-exposed to sediment

mesh envelope

PDMS fiber
PW-estimated and Directly-measured Bioaccumulation

Leptocheirus plumulosus

![Graphs showing measured vs. predicted bioaccumulation for different compounds](image)

- **TrCB**: $r^2 = 0.53$
- **TeCB**: $r^2 = 0.54$
- **PeCB**: $r^2 = 0.43$
- **HeCB**: $r^2 = 0.34$
## Bioavailability Assessment: Comparison of Approaches

<table>
<thead>
<tr>
<th>Method</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
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<tr>
<td>Theoretical Modeling (e.g., BSAF)</td>
<td>Cheap and fast – uses sediment chemistry only</td>
<td>Highest uncertainty\nLeast site specificity.\nCommonly over predicts.</td>
</tr>
<tr>
<td>Direct Measurement (e.g., laboratory bioaccumulation test)</td>
<td>Allows for site-specific determinations\nSite species may be used\nStandardized and validated approach</td>
<td>Costly, complex and lengthy.\nComplicating factors: variability across species, sediment avoidance, metabolism, health of organisms, tissue mass requirements.</td>
</tr>
<tr>
<td>Passive Sampler (e.g., SPME)</td>
<td>Cheaper than direct measurement.\nCan provide a common unbiased analysis approach across sites.\nIn situ deployment far simpler and cheaper than caged organisms.\nCan be modeled or calibrated to predict bioaccumulation.\nIdeal for intense spatial and temporal site characterization.</td>
<td>Lack of standard methods.\nUncertainty in establishing when equilibrium occurs.\nUncertainly in predicting bioaccumulation in species of concern.</td>
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