Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment: Status and Needs

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Problem Statement

Sediments serve as both a sink and a reservoir for persistent chemical contaminants, some of which are bioavailable or become bioavailable as conditions change naturally or anthropogenically. For instance, metals bioavailability can change in estuaries depending on seasonal changes in the influences of riverine flows and oceanic tides (Geesey et al., 1984). Bioturbation (mixing and movement of sediments by organisms) can also affect bioavailability of sediment contaminants by increasing oxygen and nutrient exchanges, and increasing exchange of contaminants with overlying water. Increased or sufficient bioavailability of contaminants can result in bioaccumulation and, depending on the contaminant and level of bioaccumulation, can also result in toxicity and/or in transfer to consumers through dietary uptake. In the case of certain contaminants (i.e., arsenic, mercury, methyl mercury, PCBs, DDT, DDE, toxaphene), biomagnification up the food chain can occur, affecting higher trophic levels (Suedel et al., 1994; USACE, 1995).

Bioaccumulation of toxic persistent organic contaminants by aquatic organisms is a concern for several federal agencies, including the U.S. Environmental Protection Agency (EPA), U.S. Army Corps of Engineers (USACE), National Oceanic and Atmospheric Administration (NOAA), U.S. Fish and Wildlife Service (FWS), and U.S. Geological Survey (USGS). EPA's National Sediment Quality Survey (USEPA, 1997a) has shown that these contaminants are widely distributed in sediments throughout the United States. The National Study of Chemical Residues in Fish (USEPA, 1992a) has demonstrated that these compounds are detectable in fish tissues, and many states have issued fish consumption bans as a result of bioaccumulative compounds reaching concentrations in fish tissue that may pose a threat to humans that consume them (USEPA, 1997b). For these reasons, EPA and other Federal and State agencies have identified a need to find solutions to problems associated with bioaccumulative compounds in sediments.

Scope of the Document

The EPA document, "*Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment: Status and Needs*" is intended to summarize the current status of our knowledge of bioaccumulation and recent developments in bioaccumulation research that might improve our ability to use bioaccumulation testing to evaluate sediment quality. Chapter 2 discusses the information compiled in chemical-specific summary tables (Appendix) that represent bioaccumulation research conducted during the past 10 years. The summary tables contain information associating the presence and quantity of potentially bioaccumulative chemicals in sediment with uptake in the tissues of aquatic and terrestrial organisms and with the effects of those chemicals on the organisms. Chapter 3 discusses factors affecting the bioavailability of sediment-associated contaminants. Chapter 4 describes methods and techniques that have been developed for measuring and modeling bioaccumulation. Chapter 5 presents brief synopses of current research on and uses of bioaccumulation testing in several Federal agency programs to support regulatory activities. Finally, Chapter 6 summarizes further research needs for the development of guidance for interpreting bioaccumulation of persistent organic pollutants to assist in protecting aquatic and terrestrial biota and humans from toxic effects of bioaccumulative chemicals in sediments.

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Purpose

A number of sediment assessment methods have been developed to determine the bioaccumulation potential of contaminants in sediments, but overall guidance on interpretation of test results in the evaluation of ecological and human health effects is lacking. To begin to address this concern, EPA's Office of Science and Technology (OST) and Office of Solid Waste (OSW) formed a "Bioaccumulation Analysis Workgroup" consisting of 40 Headquarters and regional participants. This workgroup has overseen the production of the present "status and needs paper," the purpose of which is to provide background information and report on the status of bioaccumulation testing and interpretation in various EPA programs (and other federal agencies). EPA's Office of Water envisions that the paper will serve as the basis for EPA-wide cross program guidance on interpretation of bioaccumulation tests for the purpose of sediment quality assessment. Ultimately, integration of interpretable bioaccumulation tests into a regulatory decision-making framework will be required, with the understanding that this would be subject to case-specific modifications based on individual program needs.

Regulatory Uses

A brief synopsis of possible uses of bioaccumulation data in EPA programs implementing a variety of statutes is presented on page 7-9. More detailed information on how bioaccumulation data is used by various programs is provided in Chapter 5. Typical applications of bioaccumulation guidance might be the characterization of sediment contamination at Superfund sites, the verification of contaminants of concern in sediment for purposes of NPDES permitting, or the selection of disposal options for dredged material.

The Office of Enforcement and Compliance Assurance (OECA) is responsible for developing and implementing enforcement and compliance assurance strategies for the National Environmental Policy Act (NEPA) and other federal regulations. As such, OECA may use bioaccumulation data under a broad range of statutes to determine the environmental acceptability of proposed Federal actions.

The Office of Prevention, Pesticides, and Toxic Substances (OPPTS) uses the results of bioaccumulation tests to support review of new and existing chemicals under the Toxic Substances Control Act (TSCA) and the registration/re-registration of chemicals under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). In addition biaccumulation information may be used to provide guidance on the design of new chemicals to reduce bioavailability and partitioning of toxic chemicals to sediment.

The Office of Solid Waste and Emergency Response (OSWER) is responsible for controlling hazardous wastes and remediating hazardous waste sites under the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response Compensation and Liability Act (CERCLA). Under CERCLA, the Office of Emergency and Remedial Response (OERR)—the Superfund Program—uses sediment assessment methods, including bioaccumulation data, as a standard part of initial sampling during the preliminary site assessment and the more in-depth remedial investigation/feasibility study for Superfund sites where sediment contamination may be present. Under RCRA, OSW is preparing a rule that addresses listed hazardous wastes, and mixtures of and residues derived from managing the hazardous wastes that pose low risks to human health and the environment. The rule will establish chemical-specific concentrations in wastes to be eligible for a self-implementing exemption from the hazardous waste management system requirements under Subtitle C of RCRA. A risk-based methodology is under development that will be used as the basis for the exit concentrations. The methodology considers the bioaccumulative potential of relevant chemicals in the evaluation of potential exposures from multiple pathways, in multimedia, and from a variety of waste management units.

In response to the Hazardous and Solid Waste Amendments of 1984 (HSWA), which amended RCRA, and the Pollution Prevention Act of 1990 (PPA), EPA released the Waste Minimization National Plan (WMNP) in November 1994. The WMNP focuses on reducing the generation and subsequent release to the environment of the most persistent, bioaccumulative, and toxic chemicals in hazardous wastes. One of the objectives of the WMNP was to develop a flexible risk-based screening tool that would assist stakeholders in identifying source reduction and recycling priorities. EPA committed to fulfill this objective by developing a tool that would prioritize chemicals based on their persistence, bioaccumulation potential, toxicity, and quantity. This screening tool—the Waste Minimization Prioritization Tool (WMPT)—has been developed by OSW and the Office of Pollution Prevention and Toxics (within OPPTS). It is currently under public review.

The Office of Water (OW) is responsible for EPA's water quality activities, which represent a coordinated effort to restore the nation's waters. The functions of this program include developing national programs, technical policies, and regulations relating to drinking water, water quality, and ground water; establishing environmental and pollution source standards; and providing for the protection of wetlands. In addition, this Office furnishes technical direction, support, and evaluation of regional water activities; enforces standards; and develops programs for technical assistance and technology transfer. The Office oversees the provision of training in the fields of water quality, economic and long-term environmental analysis, and marine and estuarine protection.

OW and the USACE developed joint technical guidance for evaluating the potential for contaminant-related impacts associated with the discharge of dredged material in the ocean under the Marine Protection, Research, and Sanctuaries Act (MPRSA) (USEPA and USACE, 1991). Similar updated guidance has been drafted for evaluating dredged material discharges in fresh, estuarine, and saline (near-coastal) waters under

Section 404 of the Clean Water Act (CWA) (USEPA and USACE, 1994). These documents employ a tiered testing protocol in which bioaccumulation data figures prominently.

Under Sections 301, 304, 306, and 307 of the CWA, the Office of Science and Technology (OST) (within OW) promulgates technology-based national effluent limitations guidelines that control the discharge of toxic chemicals and other pollutants by categories of industrial dischargers. Bioaccumulation data and modeling are used in support of this effort.

In response to the Water Resources Development Act (WRDA) of 1992 requirement that EPA conduct a national survey of data regarding sediment quality in the United States, OST prepared the National Sediment Quality Survey (NSQS) (USEPA, 1997a). For calculations related to bioaccumulation, the Survey makes use of fish tissue residue data, and models bioaccumulation from sediment using the theoretical bioaccumulation potential approach. A national database containing information in the NSQS, i.e., the National Sediment Inventory, will be maintained and updated on a regular basis so that it can be used to assess trends in both sediment quality and the effectiveness of existing regulatory programs at the Federal, State, and local levels.

Section 403 of the CWA requires determination of the quantities of and potential for bioaccumulation of released chemicals, the potential for pollutant transport, potential harm to biological communities, and direct and indirect effects on humans. The "*CWA Section 403: Procedural and Monitoring Guidance*" (USEPA, 1994) developed by the Office of Wetlands, Oceans, and Watersheds (OWOW) (within OW) discusses the qualities of target species and methods for assessing bioaccumulation; monitoring program design, including sampling of caged or indigenous indicator species; the type of tissue to be analyzed in invertebrates and fishes; and techniques for extracting and analyzing chemical contaminants. USEPA (1995) provides additional information on some of these topics.

EPA's National Estuary Program (NEP), authorized under CWA Section 320, is a national demonstration program that uses a comprehensive watershed management approach to address water quality and habitat problems in designated estuaries on the Atlantic, Gulf, and Pacific coasts and in the Caribbean. OWOW developed guidance for this program (USEPA, 1992b) which is similar to that for Section 403 (above) and which includes the design and conduct of bioaccumulation monitoring studies to link exposure and effects and to examine risks to target species and humans.

Section 402 of the CWA authorizes the National Pollutant Discharge Elimination System (NPDES) permitting program, administered by the Office of Wastewater Management (OWM) (within OW), to regulate the discharge of pollutants from point sources into navigable waters. Bioaccumulation screening methods can be used to identify chemicals of potential concern in the sediments, followed by chemical-specific analysis for confirmatory purposes. Until the States adopt numeric criteria into their standards for sediment contaminants based on bioaccumulation, the NPDES program would not require permitting authorities to include, in their NPDES permits, sediment bioaccumulation-based numeric limits. However, States have the discretion to include such limits in permits based on an interpretation of their narrative standards for toxics. To establish such permit limits, it will be necessary for permitting authorities to develop Waste Load Allocations (WLAs) for the relevant sediment contaminants.

Section 118(c)(2) of the CWA (Pub. L. 92-500 as amended by the Great Lakes Critical Programs Act of 1990 (CPA), Pub. L. 101-596, November 16, 1990) required EPA to publish proposed and final water quality guidance on minimum water quality standards, antidegradation policies, and implementation procedures for the Great Lakes System. In response to these requirements, EPA developed the Final Water Quality Guidance for the Great Lakes System; Final Rule, 40 CFR part 132; *Federal Register*, Thursday, March 23, 1995. The Guidance incorporates bioaccumulation factors (BAFs) in the derivation of criteria and values to protect human health and wildlife.

Section 118(c)(3) established the Assessment and Remediation of Contaminated Sediments (ARCS) Program to assess the extent of sediment contamination in the Great Lakes and to demonstrate bench- and pilot-scale treatment technologies for contaminated sediment. Under the ARCS program, the Great Lakes National Program Office (GLNPO) used bioaccumulation data and models to estimate comparative human health risks associated with direct and indirect exposures to contaminated sediments in the lower Buffalo River under selected remedial alternatives. It was shown that risks could be reduced under the different remedial alternatives compared to no action, particularly if dredging was the selected option.

Ongoing work in the State of Washington provides an example of the use of bioaccumulation data to implement a state regulation. Sediment Management Standards (SMS) for the State of Washington were promulgated by the Washington State Department of Ecology under Chapter 173-204 WAC in March 1991. The purpose of these standards is to "reduce and ultimately eliminate adverse effects on biological resources and significant human health threats" resulting from contaminated sediments. The State of Washington is developing human health sediment quality criteria for bioaccumulative compounds in Puget Sound sediments which will be incorporated into the State's existing SMS. These criteria (not to be confused with Sediment Quality Criteria for the Protection of Benthic Organisms proposed by EPA in the *Federal Register* in 1994) are based on standard risk assessment methodologies in conjunction with empirically derived biota-sediment accumulation factors (BSAFs).

Important Issues Involved in Generating and Interpreting Bioaccumulation Data

The following general and specific issues should be addressed before agencies can effectively consider bioaccumulative compounds when developing guidance on

sediment contamination. Each of these issues will be addressed in the "status and needs" paper.

General Issues

- What are the assumptions, applications, and limitations for each bioaccumulation methodology?
- What are the major uncertainties related to the assessment of bioaccumulation of sediment-associated contaminants?
- Do these uncertainties affect regulatory decisions? Will they be resolvable in the near term or will they require a much longer period for resolution?
- How can bioaccumulation assessment results be effectively applied to human health and ecological risk assessments?

Specific Issues

- What are the most appropriate definitions of terms related to bioaccumulation?
- What are the requirements for selecting species for bioaccumulation testing?
- What species are potentially available for use in testing?
- What are the most appropriate methods for testing bioaccumulation?
- Are there alternative tests that can be considered for assessing bioaccumulation?
- How can tissue-specific residue levels be coupled with chronic toxicity response data to develop dose-response relationships for bioaccumulative contaminants?
- How can bioaccumulation methods be used to assess population level effects (i.e., in order to allow for regulatory cost-benefit analysis)?
- How should we account for the bioaccumulation of metabolites of contaminants, such as PAHs?
- When should theoretical models be used rather than testing to assess bioaccumulation?
- How much site-specific information is required to apply models to predict bioaccumulation?
- What model parameters are more broadly applicable rather than site-specific?
- What bioaccumulation model components are essential for food chain modeling?
- Is contaminant partitioning behavior related to biomagnification?
- Can log K_{ow} help determine the trophic level at greatest risk from bioaccumulation of specific sediment contaminants?
- How should we account for differential partitioning of bioaccumulative contaminants among tissues?
- Do steady-state equilibrium model assumptions represent prevailing conditions in the long term for risk assessment purposes?
- What are the most sensitive exposure parameters that drive the outcome of human health and ecological risk assessments?
- How are different programs using bioaccumulation data and what do they need from the data to address their program responsibilities?

References

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Some Major Issues Involved in Generating and Interpreting Bioaccumulation Data

- Laboratory vs. field methods of assessing bioaccumulation
- Feeding during testing
- Uncertainties in test procedures
- Lack of test organisms
- Relationship between contaminant body burdens and adverse ecological effects
- Relationship between bioassay organisms and procedures and natural populations
- Relationship between bioassay organisms and human health

Some Major Issues Involved in Generating and Interpreting Bioaccumulation Data (cont.)

- Need to take home range/foraging area into account when estimating exposure concentrations
- Weight to give to various effects endpoints
- Presence of bioaccumulative chemicals in sediments may pose risks to aquatic life, wildlife, and humans
- Overall guidance on interpretation of bioaccumulation data in the evaluation of ecological and human health effects is lacking
- To begin to address this concern, EPA formed a Bioaccumulation Analysis Workgroup consisting of 40 Headquarters and regional participants

Bioaccumulation Analysis Workgroup is Overseeing the Production of:

- "Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment: Status and Needs"

Document will:

- Provide background information and summarize current research that might improve our ability to use bioaccumulation data to evaluate sediment quality
- Report on the status of bioaccumulation testing and interpretation in various EPA programs for the purpose of sediment quality assessment

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APPENDIX A. Chemical-specific Summaries of Bioaccumulation Information

Biaccumulation Summary Cadmium

Chemical Category: METAL (Divalent)

Chemical Name (Common Synonyms): CADMIUM **CASRN:** 7440-43-9

Chemical Characteristics

Solubility in Water: **Half-Life:**

Log K_{ow}: **Log K_{oc}:**

Human Health

Oral RfD: **Confidence:**

Critical Effect:

Oral Slope Factor: **Carcinogenic Classification:**

Wildlife

Partitioning Factors:

Food Chain Multipliers:

Aquatic Organisms

Partitioning Factors:

Food Chain Multipliers:

Toxicity/Bioaccumulation Assessment Profile

Summary of Biological Effects Tissue Concentrations for Tributyltin

Species:	Concentration, Units in:			Toxicity:	Ability to Accumulate[1]:			Source:	
Taxa	**Sediment**	**Pore Water**	**Tissue (Sample Type)**	**Effects**	**BCF**	**BAF**	**BSAF**	**Reference**	**Comments[2]**
Invertebrates									
Amphipod *Hyalella azteca*		4.8 nM[3]	110 nM/g dw (whole body)	4 week LC_{50}				[24]	L; 1 week to reach equilibrium in tissue
Polychaete *Nereis diversicolor*	455 ± 83 ng/g dw (n=5)	68.2 ± 40.6[3] ng/L (n=8)	479 ± 249 ng/g dw (pooled, whole body) (n=5)		7,023			[23]	F
Polychaete *Neanthes arenaceodentata*		100 ng/L[3]	6.27 µg/g dw (whole body)	Reduced growth and reproduction				[25]	L; 4
Polychaete *Neanthes arenaceodentata*		50 ng/L[3]	<3.0 µg/g dw (whole body)	No significant effect on survival, growth, or reproduction				[25]	L; 4
Polychaete *Neanthes arenaceodentata*		500 ng/L[3]	16.81 µg/g dw (whole body)	Significant effect on survival				[25]	L; 4
Gastropod mollusk (Common winkle) *Littorina littorea*	455 ± 83 ng/g dw (n=5)	68.2 ± 40.6[3] ng/L (n=8)	1009 ± 428 ng/g dw (pooled, whole body) (n=4)		14,795			[23]	F
Bivalve mollusk (American piddock) *Petricola pholadiformis*	455 ± 83 ng/g dw (n=5)	68.2 ± 40.6[3] ng/L (n=8)	838 ± 108 ng/g dw (pooled, whole body) (n=2)		12,287			[23]	F
Bivalve mollusk (Clam) *Scrobicularia plana*	455 ± 83 ng/g dw (n=5)	68.2 ± 40.6[3] ng/L (n=8)	3375 ± 232 ng/g dw (pooled, whole body) (n=4)		49,487			[23]	F

Summary of Agencies' Uses of Bioaccumulation Data for the Interpretation of Sediment Quality

Agency Mission and Mandates		Components of the Contaminated Sediment Management Strategy					
Program	**Relevant Statutes**	**Research**	**Assessment**	**Remediation**	**Dredged Material Management**	**Prevention**	**Outreach**
USEPA, Office of Enforcement and Compliance Assurance							
Office of Compliance						•	
Office of Federal Activities	CWA §404, NEPA §102, CAA §309, MPRSA §102 &§103, River & Harbors Act		•	•	•	•	•
USEPA, Office of Prevention, Pesticides, and Toxic Substances							
Office of Pesticide Programs	FIFRA	•	•			•	
Office of Pollution Prevention and Toxics	TSCA	•	•			•	
USEPA, Office of Research and Development							
National Health and Environmental Effects Research Laboratory							
Atlantic Ecology Div. (Narragansett)		•	•			•	•
Mid-Continent Ecology Div. (Duluth)		•	•			•	•