2. OVERVIEW OF PROCESSES AFFECTING BIOAVAILABILITY THAT SHOULD BE CONSIDERED IN DEVELOPING A CONCEPTUAL SITE MODEL

Incorporating bioavailability into risk assessments and management decisions requires recognition during the scoping phases of how bioavailability fits within the state or federal regulatory process for characterizing the level of exposure to contaminants in sediments. Bioavailability concepts are implicit in USEPA's risk-based approaches used for assessing both human health and ecological risks and are encouraged throughout the contaminated sediment management process (Greenberg and Sprenger 2008). Use of bioavailability in the sediment management process varies by state, although many use USEPA's ecological risk assessment guidance for Superfund (USEPA 1998c, 1997b, 1992b) and for human health (USEPA 1989a, 1989d).

Consideration of bioavailability begins during the scoping or problem formulation step by linking the source release(s) to potential receptors through the development of a CSM. The CSM becomes the descriptive framework in which to insert specific exposure pathways and subsequent bioavailability measures and/or models into the site characterization and risk assessment process.

While consideration of processes affecting bioavailability should be an integral part of a risk assessment and/or the risk-based management of contaminated sites, it is often neglected due to a perceived greater burden of proof for incorporating bioavailability into decision making (NRC 2003). Bioavailability information can, however, help to alleviate concerns, provide greater transparency in decision making, and allow for setting more technically defensible cleanup goals and realistic cleanup priorities.

Scoping Bioavailability in Contaminated Sediment Site Management

- Defines the extent of the site exposure boundaries, the potential chemicals of concern, and the target human health and ecological receptors
- Develops a conceptual site model that defines the source term, expected exposure pathways, and fate and transport processes from sediments to ecological and human receptors
- Identifies what tools (biological, chemical, and physical) and/or models may be available to measure whether chemicals may be bioavailable to the site receptors
- Initially considers potential site remedial alternatives and how bioavailability may be applied to determine acceptable remedial goals
- Determines how information on bioavailability can be reliably communicated, especially to the public

The following sections provide an overview of how bioavailability measures and endpoints can become an integral part of the CSM when scoping the initial investigation(s). A brief description of the process is provided, supported by links and references to important and relevant supporting information and websites. Chapters 4–8 of this document provide more detail on the tools and mechanics available for assessing the bioavailable component for each ecological or human health pathway.

2.1 Processes Affecting Bioavailability

Management of COPCs requires an understanding of how they are released from the sediment matrix, transported, and taken up by a target organism. Bioavailability tools are methodologies applied to evaluate the magnitude of release of contaminants from the solid to dissolved phase (bioaccessibility) and assess the uptake of a COPC into receptor organisms (bioavailability). Figure 2-1 is a representation of some example contaminant transport pathways between environmental compartments and native ecological receptors in a freshwater system:

- movement or transport to and into an organism by absorption of the dissolved form from sediment pore water or by the degree of accumulation through the food chain
- transport of COPCs bound to sediment particles through the skin or gut following dermal contact or ingestion
- movement of the COPC across biological membranes
- subsequent transport to the site of biological response

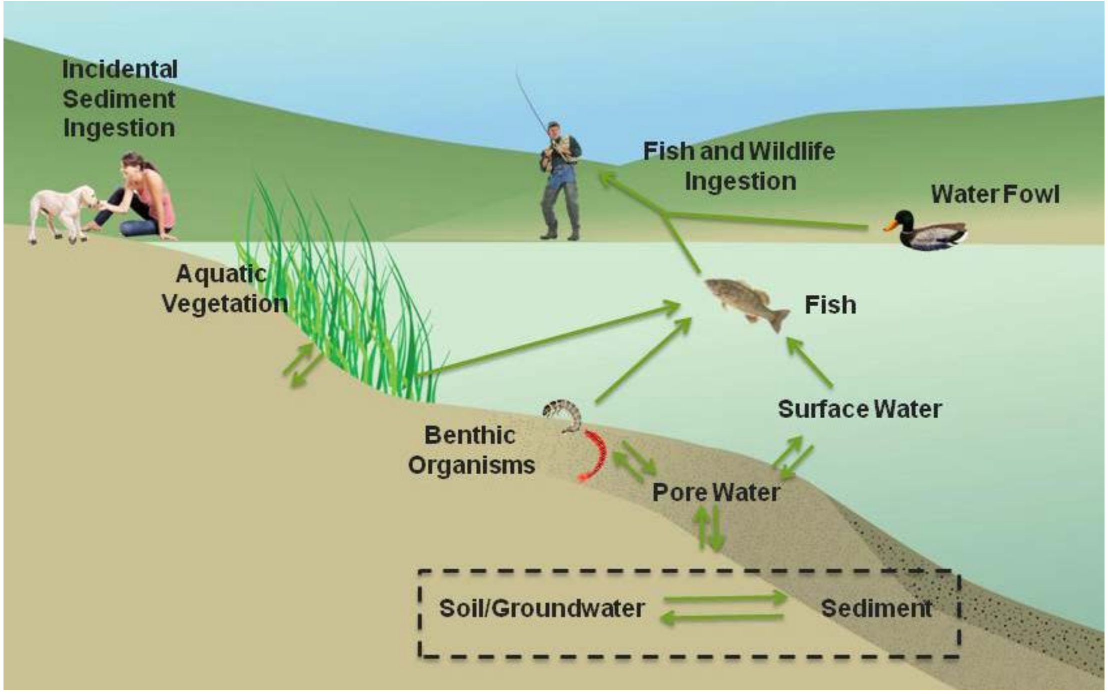


Figure 2-1. Key exposure pathways for human health risk at contaminated sediment sites.

For most aquatic risk assessments, COPC movement is either directly measured, estimated using models, and/or measured as tissue residues within the target organism.

The complexities of the sediment and aquatic systems make accurate tracking impractical, but reasonable estimates can be made. Fortunately, the ability to measure the dissolved and particulate phases of COPCs has improved considerably, and the tools described in the specific pathway chapters have a documented basis for applying these values to exposure evaluation. The general scoping process described in this section is intended to help the user understand when relatively simple considerations are adequate and where more complex tools may be required.

General processes that are important in sediment characterization can be categorized as physical, chemical, or biological. Processes that affect the bioavailability of COPCs in aquatic systems are those individual physical, chemical, and biological interactions that affect the degree of exposure and uptake of receptors to COPCs originating in the sediments. Note that some of these processes can vary due to seasonal changes. This variability should be considered in the assessment of bioavailability. A brief overview of physical, chemical, and biological processes active within sediment/surface water systems follows. These processes are also discussed in greater detail in the relevant chapters of this document dealing with different types of receptors.

2.1.1 Physical Transport Processes

Physical transport processes in sediments may include any of the following:

- advection/diffusion
- resuspension/deposition
- burial
- bioturbation
- ebullition (gas transport)

Physical processes (Figure 2-2) are generally responsible for the transport of a COPC within the sediment. Physical contaminant transport within sediment can be upward (advection/diffusion, ebullition), downward (advection/diffusion, burial), or lateral (resuspension/deposition). In water overlying the sediments, COPCs can move by the same advective and diffusive forces operating within the sediment, by sorption to/from sediments resuspended by currents or scour events, or through bioturbation caused by benthic organisms. Transport of COPCs to a site from sources such as groundwater, surface soil erosion, and outfall discharges can be considered physical processes. Hydrodynamics directly affects sediment and associated COPC transport in several ways. Sediment transport typically varies in a nonlinear fashion with hydrodynamic energy. This energy can be in the form of water flow in a river or tidal estuary or in wind-driven waves in a large lake or bay.

Advective flux in groundwater can transport COPCs directly into and through the sediment-associated pore water, as well as influence redox conditions in the sediments (USEPA 2008a). Diffusive mixing due to temperature, salinity, or pressure gradients can change COPC sorptive behavior (i.e., equilibrium partitioning) over short or long periods of time. COPC redistribution due to bed-shear caused by currents, ice scour, waves, propeller wash, or anchor drag can result in suspension of bulk sediments and can also alter partitioning relationships so that COPCs may be desorbed into the water column. These same processes can result in the release of buried nonaqueous-phase liquids (NAPLs). Finally, ebullition (gas bubble transport) may result in the upward movement of COPCs within the sediment.

2.1.2 Chemical Processes

Just as physical processes impact the distribution of sediments and COPCs in aquatic systems, so do chemical processes. It is critical that chemical processes be considered in conjunction with physical and biological processes in developing a CSM and subsequent site investigations. The bioavailability of COPCs is directly affected by the interplay of these processes.

This document considers the following chemical characteristics or processes in sediments:

- sorption/desorption
- transformation/degradation

- oxidation/reduction

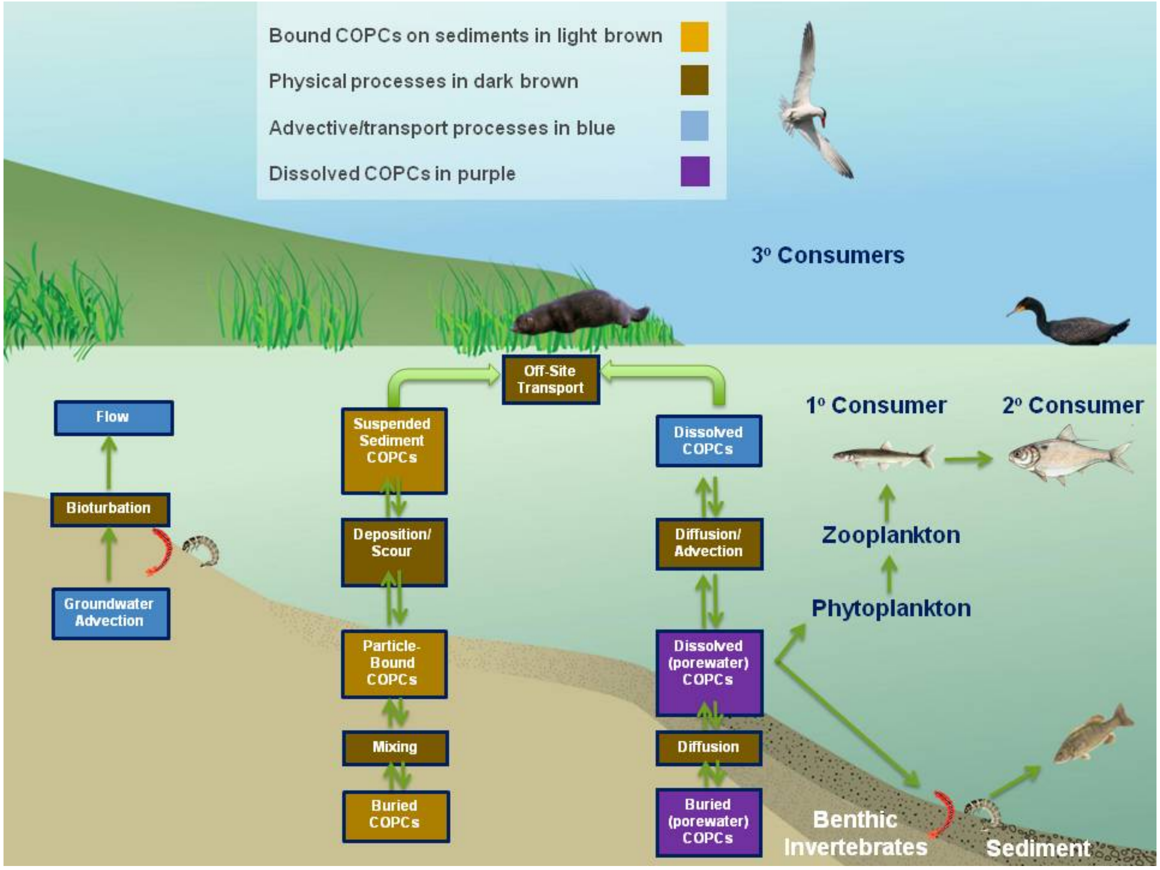


Figure 2-2. Physical transport and ecological receptor processes in a freshwater system.

Sorption/desorption processes are important in defining what "compartment" of the sediment matrix a COPC will reside in. Sediment bioavailability is often mediated by the movement of a COPC from the bulk sediment matrix (desorption) into an aqueous phase. The transfer mechanism can be either via pore water or through the gut of the organism. An example of a sorption/desorption process affecting bioavailability is the binding of polycyclic aromatic hydrocarbons (PAHs) to black carbon at a former coal gas site, rendering these compounds less bioavailable than would have been predicted (Hawthorne et al. 2007). Geochemical processes (e.g., redox/pH) are generally more important when considering inorganic COPCs. An example is the reduction of soluble Cr(VI) to the less soluble Cr(III) species (Borch et al. 2010, Graham and Bouwer 2010).

Sediment geochemical parameters—such as the quantity and type/quality of organic carbon (OC), the presence of acid volatile sulfides (AVS), the redox state of the sediment, salinity, or pH—can also influence whether a COPC is tightly bound within the sediment and unavailable for uptake, or whether it is freely dissolved and can be absorbed into organisms.

Mixing in the hyporheic zone (i.e., the region where surface water and shallow groundwater mix) can result in a release of COPCs due to changes in pressure, oxygen, temperature, oxidation state, and/or salinity. In some cases this process has resulted in increased sequestration of metals or increases in the flux of reduced metals at higher concentrations than would otherwise be expected in oxygenated surface water (e.g., arsenic in a contaminated Montana stream) (Bencala 2005). Thus, the chemical environment is a controlling determinant of potential bioavailability associated with a specific physical transport process.

2.1.3 Biological Processes

As discussed above, infaunal benthic organisms may take up COPCs from sediments and then serve as prey for higher-level organisms. Biological processes in sediments discussed in this document include the following:

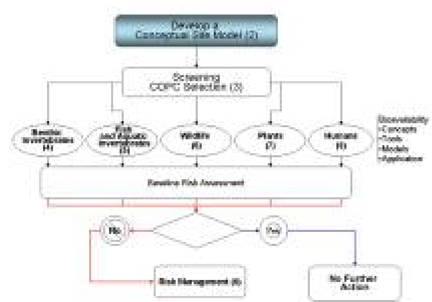
- uptake
- bioconcentration or bioaccumulation
- biotransformation

"Uptake" refers to processes whereby a COPC in sediment is transported into an organism. These processes can include movement of the COPC through the gut, external surfaces (e.g., gills), or the integument (skin) of an organism. The COPC must be bioavailable to be absorbed and subsequently transported to a site of action to have an adverse effect. The COPC may also be metabolized (biotransformed) by the organism, or it may bioaccumulate within the organism (generally within lipids or fatty tissues although some compounds preferentially bind to proteins). Finally, microbial activity within the sediment matrix may play a large role in the biotransformation or degradation of a COPC (e.g., inorganic mercury biotransformed to the more toxic and bioavailable form of methylmercury).

These processes depend on where and how an organism lives and feeds in the sediment or water column, the rate and route of COPC uptake, the relative levels of fats (lipids) within the organism, the ability of the organism to metabolize and/or excrete the chemical, as well as other factors like the age, growth life stage, and gender of the organism.

2.2 Scoping the Problem

During site assessment, one begins identifying the questions that need to be answered to evaluate and manage site risks. An initial site walkover reveals the nature of the aquatic habitat, which is important as the disposition of various COPCs may differ with the type of water body and benthic substrate (e.g., freshwater vs. saltwater, lotic vs. lentic). The scoping process identifies the early CSM, initial site COPCs, and sometimes the initial narrative remedial alternatives for a site (USEPA 1988). Fundamental steps in the scoping process are as follows:



- determine site boundaries
- review site history
- develop an initial list of COPCs
- identify ecological and human receptors and exposure pathways
- develop the early CSM

Table 2-1 lists considerations within the scoping process that are introduced in this section and discussed in more detail in subsequent chapters.

2.2.1 Determine Site Boundaries

Boundaries for a sediment site include the source release area and the extent of flow-facilitated transport of COPCs, ice scour, wind, fetch, boat disturbance, construction activities, navigational dredging, and uptake and subsequent senescence of plants. It is recommended that, if not already performed, a wetland delineation be performed by a certified wetlands biologist at applicable sites to segregate operable units. Adjacent sites, particularly upgradient sites that may also have contributed COPCs, should be identified. In addition to identification of the types of COPCs present, the vertical and horizontal extent of the COPCs must be established.

The vertical and horizontal extent of the COPCs provides an indication of the areas that may contribute to an organism's potential exposure. In this sense, bioavailability could define a physical limit on the amount or duration of exposure that could occur. For example, at small sites, sessile organisms living within the sediments would be continually exposed to COPCs. Fish, birds, or mammals, all of which have larger home ranges, would be exposed to the contaminated area (or forage on contaminated prey) only during that time period that they (or their prey) are physically within (or foraging within) that contaminated area.

2.2.2 Review Site History

The initial site scoping involves evaluation of existing information on the site background, site use, source release histories, potential COPCs released, area(s) of release, and site-specific and/or regional information available to help identify surface, subsurface, atmospheric, and biotic transport pathways (Ehrlich 1988). MacDonald and Ingersoll (2002) describe the type of information that should be identified from a review of the site history and that is needed for a site investigation. The following elements are helpful in formulating a CSM that includes an assessment of bioavailability:

- nature and quantity of COPCs released
- length of time contamination is estimated to have been in the sediment
- control or elimination sources of COPC(s)
- site or release conditions that may impact bioavailability
- other (i.e., non-site-related) potential source(s) of contamination
- physical and geochemical conditions of the site sediments
- hydrodynamic conditions at the site that may influence sediment transport
- historic and current use of the site by potential human and ecological receptors

Table 2-1. Bioavailability[1] considerations within the scoping process of a contaminated sediment site

<table>
<tr><th>Scoping element</th><th>Source of information</th><th>Activity</th><th>Bioavailability related analyses/considerations (Appendix C)</th></tr>
<tr><td>Review site history</td><td>• Available data in preliminary site assessment
• Hazard ranking documents</td><td>• Establish site boundaries, identify adjacent facilities
• Identify initial COPCs
• Identify geochemical parameters
• Understand reference (background) conditions</td><td>• Nature and extent of COPCs and exposure pathways
• COPC mobility forms and pathways
• Data gap analysis (OC, simultaneously extracted metals [SEM]/AVS, SEM – AVS, redox, salinity, and pH, which are available or which may be needed)</td></tr>
<tr><td rowspan="6">Identify site transport processes</td><td>Groundwater data</td><td>• Understand direction and flow
• Understand hyporheic zone mixing</td><td>• Flux measures into sediments via piezometers, direct pore water, solid-phase microextraction (SPME)/polyethylene (PE)/polyoxymethylene (POM) or diffusive gradient in thin films (DGT)</td></tr>
<tr><td>Surface water data</td><td>• Identify upstream sources
• Characterize surface runoff</td><td>• Type and nature of wetland habitat (e.g., freshwater, brackish, saltwater)
• Analyses of total and dissolved COPCs</td></tr>
<tr><td rowspan="3">Sediment data</td><td>Assess bulk sediment</td><td>• Analyses of COPCs, total organic carbon (TOC), SEM/AVS, SEM – AVS, and metals speciation and grain size in bulk sediment</td></tr>
<tr><td>Assess pore water</td><td>• Sample and analyze COPCs via piezometers, direct pore water measurement, dissolved organic carbon (DOC), SPME/PE/POM or DGT
• Estimate pore-water fraction by equilibrium partitioning (EqP), SEM – AVS, or other appropriate model(s)</td></tr>
<tr><td>Assess diffusive flux</td><td>• Analyses of dissolved COPC immediately above sediment/water interface
• Estimate flux based on models</td></tr>
<tr><td>Potential sediment hydrodynamics</td><td>• Assess flood or ice scour
• Assess wave/current-induced resuspension
• Assess boat propeller wash
• Assess tidal dynamics
• Assess resuspension flux</td><td>• Estimates and/or analyses of COPC desorption from resuspended sediments
• Redeposition of contaminated sediment
• Measures of total and dissolved COPCs, TOC, and DOC estimates and/or analyses of COPC desorption from resuspended sediments
• Resuspension of contaminated sediment
• Exposure to buried contaminated sediments
• Nonequilibrium conditions for organics
• Oxidation of metals
• Direct measures of COPCs in overlying waste and newly exposed sediments
• Changes in oxidation conditions
• Changes in salinity; estuarine/tidal wedge</td></tr>
</table>

[1] The processes affecting bioavailability are defined in the Glossary (Appendix F). The tools and methodologies used to assess bioavailability are described in subsequent chapter and Appendix C.

Scoping element	Source of information	Activity	Bioavailability related analyses/considerations (Appendix C)
Evaluate ecological and human health pathways and endpoints	Ecological receptor–based information	Evaluate receptor and exposure pathways: • Benthic invertebrates • Fish and water-column invertebrates • Wildlife • Plants	• Plant tissue residue analysis, plant bioassays • Community analyses, bioassays, tissue residue analysis, EqP, and biota-sediment accumulation factor (BSAF) uptake models • Tissue residue analysis (COPC and lipid), BSAF, kinetic uptake models • Tissue residue analysis (COPC and lipid), oral dose models, laboratory bioassays, field assessment of fecundity • Animal testing for bioavailability (e.g., swine), tissue residue measure (COPC and lipid), oral dose models, laboratory bioassays
	Human health–based information	Evaluate receptor and exposure pathways: • Direct contact • Ingestion	• Water analysis for COPCs, partitioning variables (e.g., octanol-water partition coefficient [K_{ow}]), oral dose models • In vitro/in vivo testing for bioavailability (e.g., swine), bulk sediment analysis, partitioning measures (e.g., organic carbon–water partition coefficient [K_{oc}]), oral and dermal dose models • Tissue residue(s), fraction of COPC available for uptake (bioaccessibility) • Identification of ingestion rates
Develop conceptual site models	• Source disposition • Ecological receptor–based pathways • Human health–based pathways	• Evaluate geochemical, physical, and hydraulic pathways • Evaluate critical receptors and exposure pathways • Evaluate exposure routes and sensitive user groups	• Identify physical processes and data needs to assess COPC availability • Identify routes of uptake into biota, transfer through the food web • Characterize consumption rates, area use factors, uptake factors, fish consumption, etc.

Text Box 2-1 presents an example of the importance of site history review. At the Mocks Pond site in Muncie, Indiana, the use of a former quarry site as an effluent settling pond for a wire-galvanizing plant resulted in the deep accumulation of a fine, heavy metal–rich sludge. While the benthic conditions in the pond bottom were not conducive to support benthic infauna or fish, the overlying water supported a diverse and healthy fish and wildlife community. In evaluating the site history, it was determined that the spent sludge was treated with lime prior to discharge, which resulted in insoluble metal hydroxides. The CSM was developed and tested based on the hypothesis that these metal hydroxides were not biologically available through dissociation in pore water or surface water and that the sediment would not support aquatic life. Confirmation of the CSM allowed for a remedial alternative that included some removal, followed by capping to improve benthic habitat.

2.2.3 Develop List of **Contaminants of Potential Concern**

A critical element of the CSM is the identification of the chemicals that may have been released at a site or may occur for other reasons within or beyond the identified site boundaries. This initial list of COPCs is evaluated in more detail and refined during the screening process that is described in Chapter 3. Understanding the potential processes affecting bioavailability associated with different classes of compounds (e.g., PAHs, chlorinated organic compounds) may lead to a better understanding of analytical requirements, exposure pathways, COPC mobility testing, and relevant toxicity (e.g., critical body residue thresholds or species sensitivity distributions).

2.2.4 Identify Ecological and Human Health Exposure Pathways

A complete CSM requires an integration of the physicochemical conditions with each of the complete ecological and human health exposure pathways. The exposure pathways for screening assessment should be set up without consideration for bioavailability (Figure 1-2), then refined with bioavailability estimates in the baseline risk assessment. For example, fish could potentially ingest sediment in an impacted lake (so this would be a potentially complete pathway), but concerns of bioavailability of COPCs would be made in the text supported by empirical data. Considerations for bioavailability assessments in exposure pathway analyses are identified in Table 2-1 and described in more detail in Chapters 4–8.

2.2.4.1 Ecological exposure pathways

Numerous federal and state guidance documents that discuss the process for conducting sediment investigations are available to download (Table 2-2). These documents should be used to obtain background information on how to scope a sediment investigation. Additional references are also provided in each individual pathway chapter as it relates to how bioavailability may fit into the exposure evaluation.

Text Box 2-1. Case Study: Mocks Pond Area, Muncie, Indiana (see Appendix D)

The importance of understanding site history in the formulation of a CSM is illustrated by the investigation and remedial actions undertaken at the Mocks Pond Area in Muncie, Indiana. Mocks Pond is an abandoned limestone quarry which had formerly received treatment sludge related to the manufacture of galvanized (zinc-coated) wire products. Review of site history determined that lime was added to neutralize the waste solutions before discharge, forming insoluble metal hydroxides. The resultant “sediment” was a very fine iron-rich material with low TOC. While constituents of interest in the pond included heavy metals (i.e., lead, zinc) at concentrations exceeding their respective sediment screening values, previous testing suggested that the materials deposited in the bottom of the pond were stabilized and not biologically available.

Ecologically, the pond bottom consisted principally of unconsolidated sediment that was largely devoid of organic material and bottom-dwelling insects. As a result, bottom-feeding fish species (e.g., carp, catfish) were not common in the pond. Also, despite the presence of shallow, permanently submerged habitat, the margins of the pond were devoid of rooted or floating vascular vegetation (e.g., cattails). In contrast to the sediment conditions, the pond contained a relatively diverse and healthy water-column aquatic community, including a variety of pelagic fish, snapping turtles, and other turtle species. Belted kingfishers, great blue herons, and other aquatic-dependent birds were observed foraging on and nesting within the area. Mammals using the pond included raccoon and potentially river otter. Institutional controls for human exposure were in place in the form of a large fence surrounding the site.

The CSM was formulated and tested based on the hypothesis that sludge-sediment itself would not support aquatic life and that the metal hydroxides were not biologically available through dissociation in pore water or surface water. While the physical/chemical conditions in the deposited materials were not conducive for benthic-dependent insects or fish, metals in the sediments were biologically unavailable to upper trophic level organisms. A remedial goal of the project was to demonstrate that the metals present in the impacted sediment were biologically unavailable following dredging to a clear water depth of 10 feet and placement of a sand cap over the entire pond bottom to improve aquatic habitat for future recreational use.

Bioavailability was evaluated as part of a human health and ecological risk assessment by measuring metals in the whole bodies and filets of pelagic fish species. The risk assessment activities determined that select metals tissue were identified in fish tissue at concentrations that may pose a significant consumption risk to recreational anglers.

Bioavailability was subsequently evaluated following implementation of the remedy as part of a post-remedial monitoring program designed to monitor cap performance (i.e., ability to restrict the migration of constituents into the biotic zone) by measuring metals concentrations in pore water. Large-volume “peepers” were used to collect pore-water samples. These devices consisted of dialysis tubing filled with reagent grade water placed into a protective sheath, and then inserted to a depth of 10 cm into the sediment. Results from the post-remedial monitoring confirmed that metals were tightly sequestered and not partitioning into pore water or surface water.

Peeper sampler (l), sampler installation (r).

Table 2-2. Links to guidance on conducting sediment investigations and risk assessments

USEPA	
Contaminated Sediment Evaluation Guidance	
EPA's Contaminated Sediment Management Strategy (USEPA 1998a)	http://itrcweb.org/contseds-bioavailability/References/PCBContaminatedSedimentsStrategy.pdf
"Contaminated Sediments In Superfund"/ "Guidance Documents, Fact Sheets and Policies"	www.epa.gov/superfund/health/conmedia/sediment/documents.htm
Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual (USEPA 2001c)	http:\\itrcweb.org\contseds-bioavailability\References\EPA_823_F_01_023.pdf
Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA (USEPA 1988)	www.epa.gov/superfund/policy/remedy/pdfs/540g-89004-s.pdf
A Guidance Manual to Support the Assessment of Contaminated Sediments in Freshwater Ecosystems, 3 vols. (MacDonald and Ingersoll 2002)	Vol. I. *An Ecosystem-Based Framework for Assessing and Managing Contaminated Sediments*: www.clu-in.org/download/contaminantfocus/sediments/guidance-assessment-freshwater-epaVolumeI.pdf Vol. II. *Design and Implementation of Sediment Quality Investigations*: www.clu-in.org/download/contaminantfocus/sediments/guidance-assessment-frehwater-epa-VolumeII.pdf Vol. III. *Interpretation of the Results of Sediment Quality Investigations*: www.clu-in.org/download/contaminantfocus/sediments/guidance-assessment-freshwater-epa-VolumeIII.pdf
Contaminated Sediment Remediation Guidance for Hazardous Waste Sites (USEPA 2005a)	www.epa.gov/superfund/health/conmedia/sediment/pdfs/guidance.pdf
Risk Assessment	
Wildlife Exposure Factors Handbook, 2 vols. (USEPA 1993)	Vol. I.: http://www.itrcweb.org/contseds-bioavailability/References/10004SMD.pdf Vol. II.: http://www.itrcweb.org/contseds-bioavailability/References/WEFHV2.PDF
"Superfund Risk Assessment" Home Page	www.epa.gov/oswer/riskassessment/risk_superfund.htm
Guidelines for Ecological Risk Assessment (USEPA 1998c)	http://www.itrcweb.org/contseds-bioavailability/References/ECOTXTBX.pdf
Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments (EPA 1997b)	http://www.epa.gov/risk/ecological-risk-assessment-guidance-superfund-process-designing-and-conducting-ecological-risk
ECO Update Bulletin Series	http://epa.gov/oswer/riskassessment/ecoup
State	
Guidance for Applying the Sediment Sampling and Analysis Requirements of Chapter NR 347, Wisconsin Administrative Code	http://www.itrcweb.org/contseds-bioavailability/References/nr347guidancefinal.pdf
Guidance for Sediment Quality Evaluations (NJDEP 1998)	http://www.itrcweb.org/contseds-bioavailability/References/ecological_evaluation.pdf

Sediment Sampling and Analysis Plan Appendix: Guidance on the Development of Sediment Sampling and Analysis Plans Meeting the Requirements of the Sediment Management Standards (Chapter 173-204 WAC) (WDOE 2008)	http://www.itrcweb.org/contseds-bioavailability/References/0309043.pdf
Overview of Freshwater and Marine Toxicity Tests: A Technical Tool for Ecological Risk Assessment (California Office of Environmental Health Hazard Assessment, 2004)	http://oehha.ca.gov/media/downloads/ecotoxicology/general-info/marinetox3.pdf
"Spatial Analysis and Decision Assistance" (University of Tennessee Institute for Environmental Modeling)	www.tiem.utk.edu/~sada/index.shtml
Guidance for Ecological Risk Assessment: Levels I, II, III, IV (Oregon Department of Environmental Quality, 1998)	www.deq.state.or.us/lq/pubs/docs/cu/GuidanceEcologicalRisk.pdf
Guidance for Assessing Bioaccumulative Chemicals of Concern in Sediment (ODEQ 2007)	www.deq.state.or.us/lq/pubs/docs/cu/GuidanceAssessingBioaccumulative.pdf
Guidance for Conducting Ecological Risk Assessments, Revised (OEPA 2008)	http://www.epa.state.oh.us/portals/30/rules/RR-031.pdf
A Guide to the Interpretation of Metal Concentrations in Estuarine Sediments (Florida Department of Environmental Regulation, 1988)	www.dep.state.fl.us/water/monitoring/docs/seds/estuarine.pdf
"Frequently Asked Questions Concerning the Florida Coastal Sediment Quality Guidelines" (Florida Department of Environmental Protection, n.d.)	www.dep.state.fl.us/water/monitoring/sedsfaq.htm
"Interpretative Tool for the Assessment of Metal Enrichment in Florida Freshwater Sediment" (Florida Department of Environmental Protection, n.d.)	www.dep.state.fl.us/water/monitoring/fwseds.htm
Development and Evaluation of Numerical Sediment Quality Assessment Guidelines for Florida Inland Waters (MacDonald et al. 2003)	www.dep.state.fl.us/water/monitoring/docs/seds/sqags_for_florida_inland_waters_01_03.pdf
Technical Guidance for Screening Contaminated Sediments (New York State Department of Environmental Conservation, rev. 1999)	www.lm.doe.gov/cercla/documents/rockyflats_docs/SW/SW-A-006230.pdf
Department of Defense	
Contaminated Sediment Evaluation Guidance	
Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S.—Testing Manual: Inland Testing Manual (USEPA 1998b)	http://www.itrcweb.org/contseds-bioavailability/References/Evaluation-Analytical-methods-USACE-EPA.pdf
Dredged Material Evaluation and Disposal Procedures (Users' Manual) (U.S. Army Corps of Engineers, 2008)	http://www.itrcweb.org/contseds-bioavailability/References/aqr_dmmp_user_manual.pdf

Guide for Incorporating Bioavailability Adjustments into Human Health and Ecological Risk Assessments at U.S. Navy and Marine Corps Facilities, Part 1: Overview of Metals Bioavailability (NFESC 2003b)	http://www.itrcweb.org/contseds-bioavailability/References/bioavailability01.pdf
Critical Issues for Contaminated Sediment Management (Apitz et al. 2002)	www.clu-in.org/download/contaminantfocus/sediments/critical-sediment-mgt-sedmgt.pdf
Implementation Guide for Assessing and Managing Contaminated Sediment at Navy Facilities (NAVFAC 2003)	http://itrcweb.org/contseds-bioavailability/References/ug-2053-sed-rev-2.pdf
Risk Assessment	
"Navy Guidance for Conducting Ecological Risk Assessments"	
Department of Energy	
"RAIS: The Risk Assessment Information System." (Oak Ridge National Laboratory) Several guidance documents can be found on this site describing the use of ecotoxicological benchmarks.	http://rais.ornl.gov
Data Quality Objectives	
Guidance on Systematic Planning Using the Data Quality Objectives Process (USEPA 2006a)	www.epa.gov/quality/qs-docs/g4-final.pdf
QA/QC Guidance for Sampling and Analysis of Sediments, Water, and Tissues for Dredged Material Evaluations: Chemical Evaluations (USEPA Office of Water, 1995)	http://el.erdc.usace.army.mil/dots/pdfs/epa/qaqc.pdf

While specific wildlife and exposure pathways are site dependent, four general receptor groups are evaluated (see Chapters 4–7 for more detail):

- Chapter 4: benthic invertebrates
- Chapter 5: fish and aquatic invertebrates
- Chapter 6: wildlife (aquatic dependent)
- Chapter 7: plants (aquatic)

Organisms that live in or on the sediment, generally referred to as "benthic invertebrates," are in direct contact with the sediment and in some systems form the foundation of the aquatic food web. COPCs that are bound to sediment particles may partition to pore water and be absorbed across gill membranes or may be ingested and absorbed in the gut. Fish and other organisms that prey on benthic infauna are exposed in turn to those same COPCs. Processes that govern uptake by benthic infauna are discussed in Chapter 4.

Resuspension of bedded sediments can result in release of COPCs to the water column, where the chemicals can partition to a freely available (i.e., dissolved) form and be absorbed by phyto- and zooplankton. Fish and other water-column (pelagic) organisms that consume phytoplankton or prey on zooplankton are exposed in turn to these same COPCs. Processes affecting bioavailability and measures for pelagic food webs are discussed in Chapter 5. Aquatic-dependent wildlife (e.g., birds or mammals) are principally exposed through incidental ingestion of sediment (e.g., during foraging) or consumption of contaminated fish or shellfish. Processes affecting bioavailability and measures for these receptors are discussed in Chapters 6 and 7.

2.2.4.2 Human health exposure pathways

The primary and secondary exposure pathways for human health exposures from contaminated sediments typically include direct contact with sediments and surface water and ingestion of contaminated shellfish, fish, or less often plants (e.g., wild rice) and wildlife (waterfowl). Figure 2-3 shows an example of a human health food-web model. Chapter 8 discusses processes affecting bioavailability and measures for humans in more detail.

RAOs for human health exposure at contaminated sediment sites are most often based on the management of unacceptable lifetime cancer or noncancer risks from the consumption of fish or shellfish. Sediment cleanup levels are back-calculated from unacceptable tissue concentrations using models that range in complexity from simple BSAFs to sophisticated toxicokinetic models that are linked to systemwide fate and transport models. Because the primary risk pathway to humans is ingestion of organisms that have accumulated contaminants from the sediment, the most significant processes affecting bioavailability are addressed in that initial uptake. The processes and tools for evaluating this initial uptake are covered in more detail in this guidance in the chapters addressing risk to those receptors. Chapter 8 summarizes the human health exposure assumptions in more detail, with references to pertinent sections of Chapters 4–7.

2.2.5 Develop CSM

Assessing exposure and uptake requires formulating a CSM that considers the individual exposure pathways linking sources to potential receptors. Site-specific investigations of contaminated sites, as defined in USEPA's *Risk Assessment Guidance for Superfund* (RAGS) (USEPA 1989d), are structured to incorporate measures of site-specific bioavailability through each step of the assessment process.

A CSM is especially important at sediment sites because the interrelationship of soil, surface water, groundwater, sediment, and human and ecological receptors can be complex. Sediment and soil may be subject to erosion, and both can be transported by natural events (e.g., floods) or man-made disturbances from engineering changes in a waterway. Because sediment is a dynamic medium subject to a wide range of natural phenomena, it is important to understand what chemicals may be bound and what may be bioavailable to human and ecological receptors.

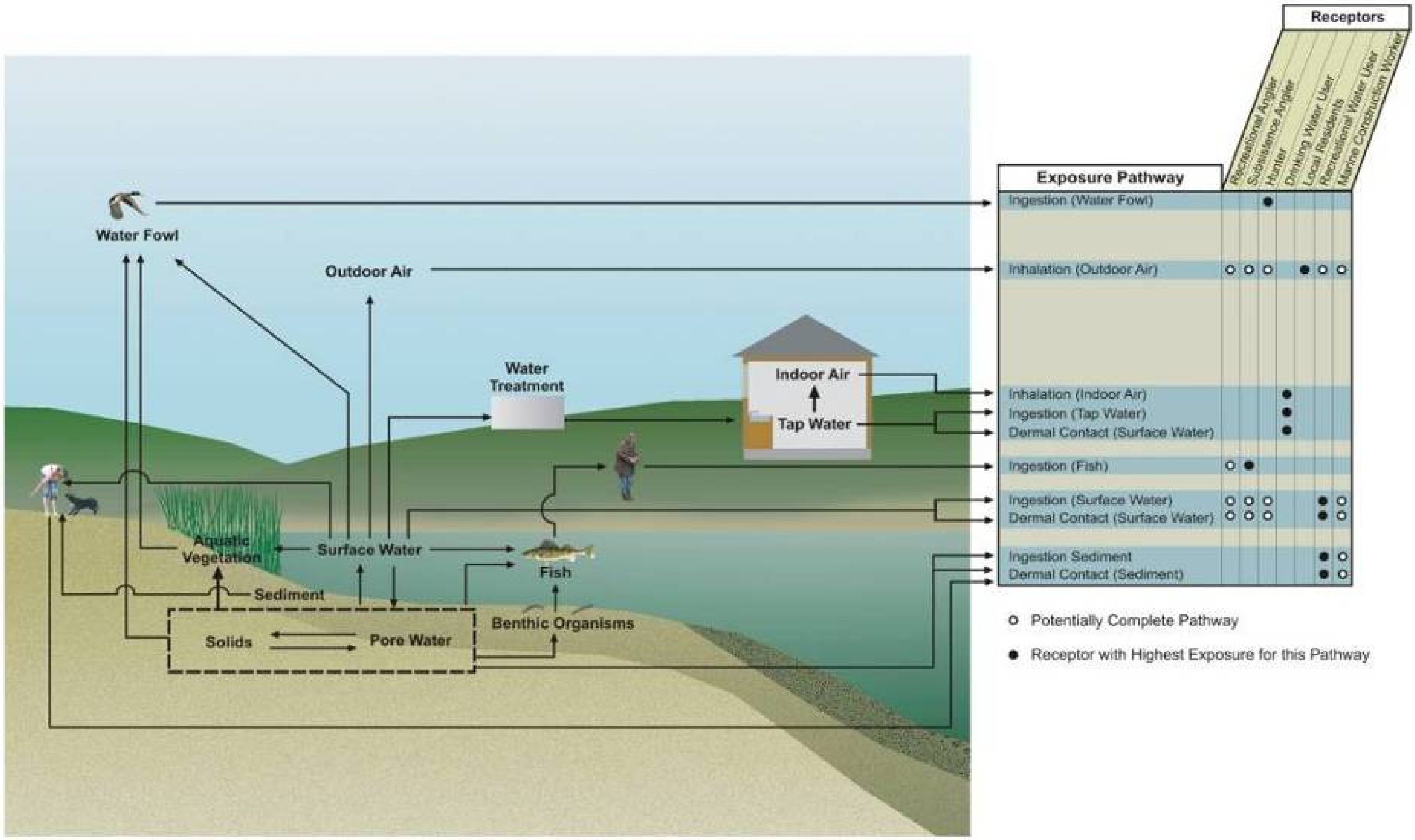


Figure 2-3. Potential source media, chemical migration routes, receptors, and exposure pathways relevant to human health (Lower Fox River).

The importance of a CSM in identifying the significance of bioavailability considerations in sediment management decision making is illustrated by the Lake Hartwell polychlorinated biphenyl (PCB) Superfund site in South Carolina (Text Box 2-2). The CSM identified the important physical, chemical, and biological processes for PCB transfer through the food chain that may cause risk to human health and ecological receptors. Based on the CSM, the natural burial of PCBs by clean sediment coming into the system was demonstrated to be reducing the bioavailable concentrations in bedded lake sediments. Based on this mechanism of decreased PCB bioavailability, USEPA selected monitored natural recovery (MNR) with long-term monitoring as the preferred remedy.

2.3 Data Quality Objectives

Incorporating bioavailability considerations into a CSM supports the development of testable hypotheses around which field data collection, laboratory testing, and modeling activities can be structured. Formulation of DQOs provides a systematic structure for defining the criteria that a data collection design should satisfy, whether or not they include bioavailability considerations. DQOs include when and where to collect samples, what parameters need to be tested, the tolerable level of decision error for the study, and how many samples to collect. Balancing risk and cost in an acceptable manner should be considered at this step in the process (see http://vsp.pnl.gov/dqo, DOE 2009). USEPA also provides an example DQO process germane to planning bioavailability assessments in the document *Systematic Planning: A Case Study for Hazardous Waste Site Investigations* (www.epa.gov/quality1/qs-docs/casestudy-final.pdf, USEPA 2006b).

After completion of a CSM wherein the preliminary COPCs and potential exposure pathways have been identified and the DQOs have been established, the screening process should occur. Chapter 3 briefly describes the application of a screening process to determine whether additional investigations are required to refine the CSM, the list of COPCs, and the exposure pathways at the site.

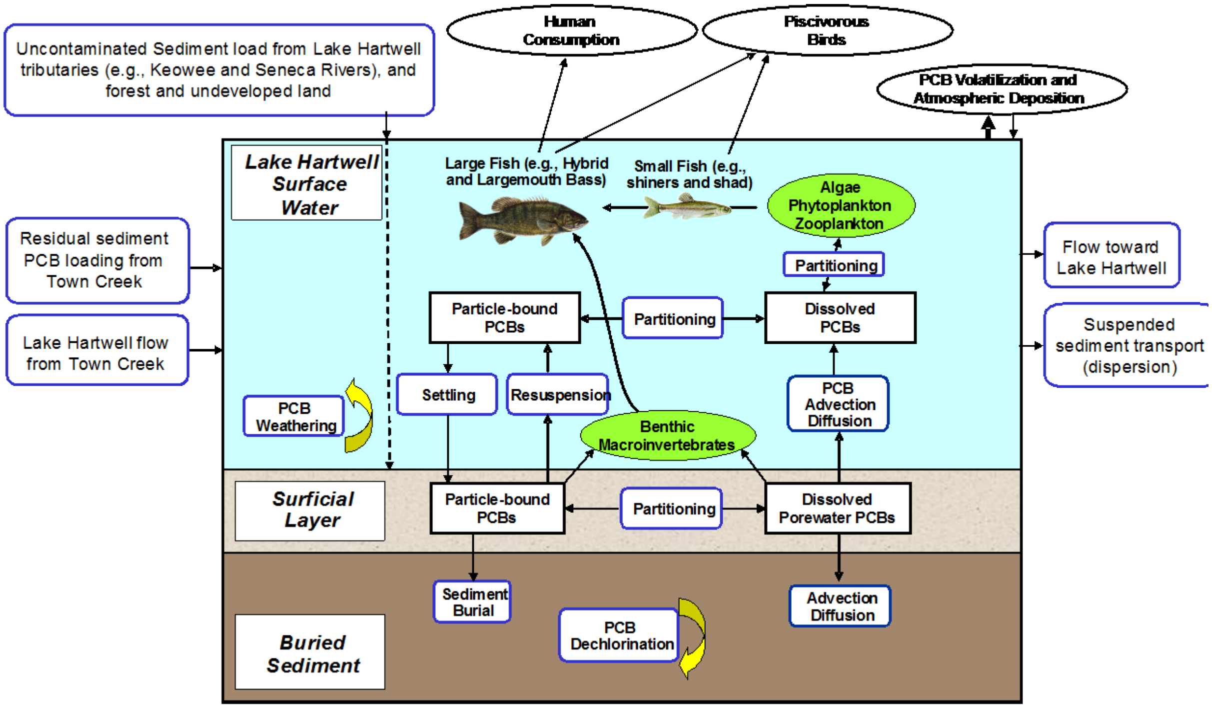
2.4 Community Stakeholder Identification, Engagement, and Contributions

This section provides information to help affected individuals and groups participate more effectively in the site evaluation and remediation process for sites in which bioavailability processes are pertinent. In this document community stakeholders (stakeholders) include affected tribal sovereign nations, community members, members of environmental and community advocacy groups, and local governments.

Affected stakeholders are not necessarily limited to those on or immediately adjacent to the site. In the case of contaminated sediments in a river, affected stakeholders may include parties far removed from the source of contamination. Tribal sovereign nations may have treaties or other pacts with the federal government that grant them fishing, hunting, or access rights in places that are not necessarily near their present-day communities. This consideration is especially important in the identification of affected tribal sovereign nations.

Text Box 2-2. Application of a CSM at Lake Hartwell PCB Superfund Site

Monitored natural recovery was the selected remedy for PCB-contaminated surface sediments in approximately 730 acres of the Twelve Mile Creek Arm of Lake Hartwell, South Carolina. The Sangamo-Weston Plant, situated on Town Creek, was responsible for PCB discharges from plant effluent and improper waste-disposal practices. Particulate-sorbed PCBs were transported through Town Creek to Twelve Mile Creek and were deposited into the Lake Hartwell sediment bed. The CSM developed for the remedial investigation identified the important physical, chemical, and biological processes affecting the bioavailability of PCBs in the Lake Hartwell food chain. The CSM (below) highlights the pathways PCB contamination follows from sediment to humans.



(*Source:* ESTCP 2009)

An important component of the CSM identified deposition of clean up-river sediments into the lake as a mechanism that would bury contaminated sediments, making them physically unavailable. Monitoring studies confirmed a steadily decreasing surface sediment PCB concentrations due to burial, mixing, dispersion (Brenner et al. 2004) and dechlorination (Magar et al. 2005a, 2005b). Sediment age dating indicated that the majority of surface sediments in the Twelve Mile Creek arm of Lake Hartwell would reach the 1 mg/kg cleanup goal between 2007 and 2011 (USEPA 2004b). Based on these data, the EPA selected MNR with long-term monitoring as the remedy.

The CSM was also instrumental in assisting with the design of the long term monitoring program. PCB concentrations are measured in surface sediment samples, caged freshwater clams (*Corbicula* spp.) exposed for 28 days, forage fish (gizzard shad/blueback herring, threadfin shad, and bluegill), and game fish (largemouth bass, channel catfish, and hybrid bass) (USEPA 1994d). Although surface sediment PCB concentrations have declined as predicted, PCB concentrations in fish tissue remain elevated, suggesting incompletely characterized and controlled exposure pathways. Additional investigation of exposure pathways are planned to update the CSM (ESTCP 2009).

For contaminated sediment sites, effective evaluation and treatment of environmental contamination require community engagement early in the process. Community involvement is particularly important for technically challenging situations where bioavailability assessments associated with contaminated sediments have not yet been well established and the approach will therefore necessarily involve some uncertainties. The contamination itself may involve a complex environment with many coupled systems and processes, and the relevant natural phenomena such as bioavailability, bioaccumulation, and biomagnification may be difficult to understand. Furthermore, the number of communities, states, and tribal sovereign nations affected by a contaminated sediment site may be large, encompassing a wide geographic area.

For effective community stakeholder identification and involvement, several important questions should be asked early in the process of investigating a site:

- Who are the stakeholders, and what is their interest in the site cleanup?
- What resources are the stakeholders trying to protect?
- What is the best method to communicate with the stakeholders?
- In what manner are these resources at risk, and can that risk be quantified?
- How will stakeholders be involved in deciding what is acceptable risk?
- Historically, what was the use of the site, and is this culturally significant to the stakeholders?
- What is the current use of the site, and what is the vision for the future use of the site?
- How will stakeholders be involved in the assessment, project planning, evaluation, and closure processes?

Individual states and the tribal sovereign nations may also recognize Native American tribes that are not currently recognized by the federal government. A list of federally recognized tribal sovereign nations can be found at http://edocket.access.gpo.gov/2008/E8-6968.htm. A list of Native American tribes not federally recognized can be found at www.kstrom.net/isk/maps/tribesnonrec.html.

2.4.1 Engagement Considerations

It is desirable to establish early and frequent communication between the project team and the stakeholders. As a project evolves and the scope of the project becomes better defined, stakeholder roles may change. Nevertheless, it is valuable to define roles and responsibilities early in the process and to agree on the methods that will be used for effective communication. Stakeholders must have an active role in the decision-making process.

Building effective relationships with stakeholders and involving stakeholders in collaborative decision making are essential components of a successful cleanup effort. All interested stakeholders must have access to critical information and the opportunity to be partners in technology development decisions during the planning, evaluation, and implementation processes. Stakeholders often have valuable information about site characteristics and history that can enhance the evaluation process and improve the quality of remediation decisions. Technology development and deployment decisions need to take into account the uses of affected water bodies, including fishing patterns, consumption of aquatic species, and cultural and ceremonial practices. It is important to achieve consensus with stakeholders about the intended end use of the site.

In the evaluation of the impact of the contamination and cleanup, it is important to keep in mind that not all of the affected communities may have comparable lifestyles. Lifestyle choices lead to different levels of risk, and communities may be disproportionately affected. For example, stakeholders with high ingestion rates of fish may be subject to greater risk than others. It is essential to establish what species are being fished and the methods used in their preparation for consumption. Certain stakeholders may have rights to fish by traditional methods that are prohibited for commercial fishermen. These may include dragnet fishing, which pulls up sediments. Thus, risks associated with contaminated sediments may be greater for those who fish by this traditional method than for commercial or sport fishermen.

2.4.2 CONTRIBUTION CONSIDERATIONS

Stakeholders are likely to ask questions about the risks associated with specific technological solutions. Concerns might include questions about whether the remedy will lead to mobilization of the contaminants and how much contamination is being left in place. Stakeholders may also be concerned about making sure that there are sufficient data/support that any residual contamination will not pose an unacceptable risk (because it is not bioavailable) and will remain so in the future.

The most effective way to respond to such concerns and build public trust is to include stakeholders in the evaluation of the contamination problem and in the formulation of a remediation strategy. Open public discussion is particularly important in the evaluation of the problem and of potential technological solutions because the approaches to contaminated sediment problems are still under development and technological uncertainties remain. Stakeholders also need to be involved in the on-site observation and evaluation of the cleanup process.

Stakeholder involvement contributes to the overall success of a sediment management decision. Involvement of stakeholders in all stages of the process helps to build support for the cleanup effort and also helps to reduce the possibility of political and legal barriers to successful remedies.