Incorporating Bioavailability Considerations in the Evaluation and Remediation of Contaminated Sediment Sites

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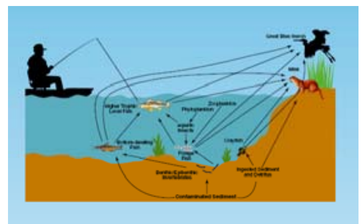
Contaminated Sediments Team



ITRC is the Interstate Technology and Regulatory Council

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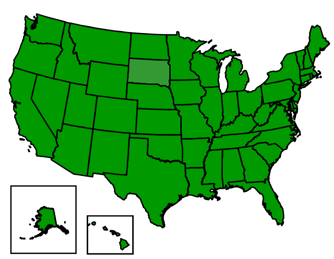
Who are the ITRC

State regulators with representatives from all 50 States and DC

Representatives from:

- **Federal government**
- **Industry**
- **Consultants**
- **Academia**
- **Community stakeholders**



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Objective of the Web-based Technical and Regulatory Guidance

- Assists State Regulators and practitioners in understanding and incorporating the fundamental concepts of bioavailability in contaminated sediment management. Including:
  - Developing a Conceptual Site Model (CSM) that includes bioavailability assessments
  - Available tools to assess bioavailability
  - Remedial goals based on bioavailability

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Contaminated Sediments ITRC Team Composition

- States
  - Alabama
  - California
  - Delaware
  - Florida
  - Kentucky
  - New Jersey
  - New York
  - Oklahoma
  - Oregon
  - Pennsylvania
  - Washington
- Federal Agencies
  - Navy
  - Army
  - EPA Including Region 2 & 5
  - USACE
  - DOE
- Industry
  - Geosyntec
  - W.L. Gore
  - Tetra Tech
  - Haley and Aldrich
  - Langan
  - URS
  - Arcadis
  - Battelle
  - WRI
  - Alcoa
  - DuPont
  - Columbia Analytical Services
  - M.W. Global
  - Burns & McDonnell
  - AECOM
  - CDM
  - Alta Environmental
  - Brown and Caldwell
  - Test America labs
  - SAIC
  - Kleinfelder
  - Malcolm Pirnie
  - Neptune and Co.
- Universities
  - Purdue
  - U. of Florida
- Community Stakeholders
  - Mtn Area Land Trust

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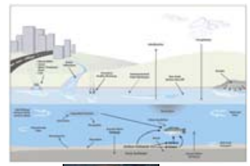
Web-based Guidance Outline

- Introduction and Background on Bioavailability
- Overview of Bioavailability Processes
- Bioavailability Pathway Exposure Assessment
  - Screening
  - Background
  - Pathway Exposure Assessment
    - Benthic Invertebrates
    - Fish and Water Column Invertebrates
    - Wildlife
    - Plants
    - Human Health
- Risk Management Decision-making
- Case Studies



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What is Bioavailability?

"…individual physical, chemical, and biological interactions that determine the exposure of plants and animals to chemicals associated with soils and sediment (National Research Council, 2003)."

Specifically, bioavailability addresses the fact that only a fraction of the contaminant concentration present in the environment may be taken up or result in an effect on an organism!

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How can Bioavailability make a difference?

- If contaminants are not physically accessible, or chemically or biologically available, they should not be included in the calculation of risk
- This can optimize the extent of cleanup required to be protective and can be an important factor in balancing the risks caused by remedial action with the risks addressed by remedial action
- Can provide optimization of remedial approach and cost

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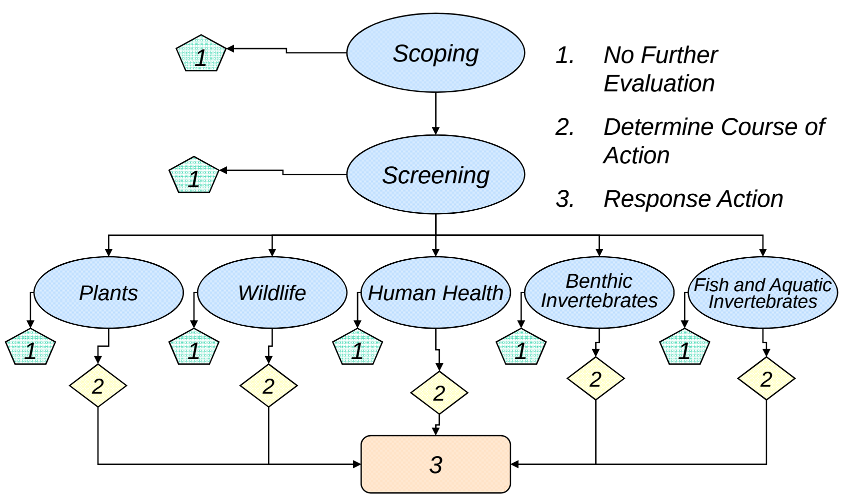
Contaminated Sediment Assessment Approach



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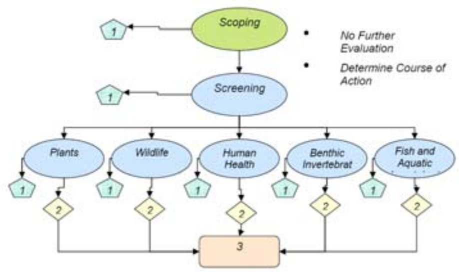
Scoping

- Review Site History
- Determine Site Boundaries
- Determine list of Contaminants of Potential Concern
- Develop initial Conceptual Site Model (CSM)



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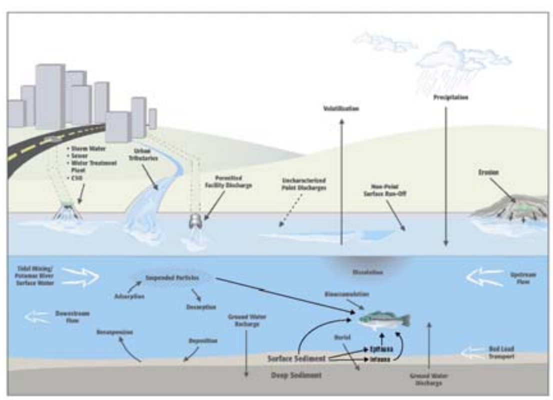
Conceptual Site Model
Anacostia River

Develop a conceptual site model (CSM) that defines the expected fate and transfer pathways of chemicals of concern from sediments to ecological and human health receptors



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Processes to Consider During Scoping

Identify the tools (biological, chemical, and physical) and models available to measure and test whether those chemicals may be bioavailable to the site receptors

Physical processes
- Bed Transport
- Resuspension/ deposition
- Bioturbation
- Advection/diffusion
- Grain size COPC distribution
- Burial

Chemical processes
- Sorption/desorption
- Transformation/ degradation
- geochemical (carbon, salinity, pH, Redox)

Biological processes
- Uptake
- Biotransformation
- Bioaccumulation
- Mode of action
- Critical body burden

Explicitly consider the potential site actions and end use, and how bioavailability may be applied in management decisions

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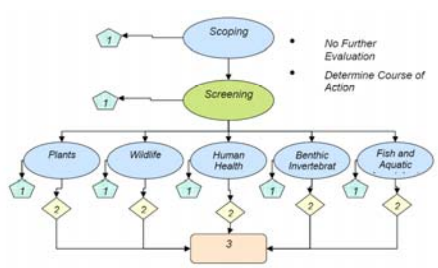
Screening

- Conservative endpoints
- Determine if there is a need for further investigation
- Site specific and benchmark-based

<u>Screening values have been established</u>
- EPA and various regions
- NOAA
- DOD
- ORNL
- Some States



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Screening and Bioavailability

- Consideration of bioaccumulation, biomagnifications, & normalization of TOC in bulk sediments, can be applied within the screening process under some states regulatory programs
  - Example: Wisconsin Dept. of Natural Resources Sediment Guidance
    "In the case of nonpolar organic compounds such as PAHs, PCBs, dioxins/furans, and chlorinated pesticides, the bulk sediment concentrations can be normalized to the TOC content for site-to-site comparison purposes by dividing the dry weight sediment concentration by the percent TOC in the sediment expressed as a decimal fraction."
- Prediction of toxicity is better made by incorporating bioavailability in later stages of the site investigation using site specific considerations

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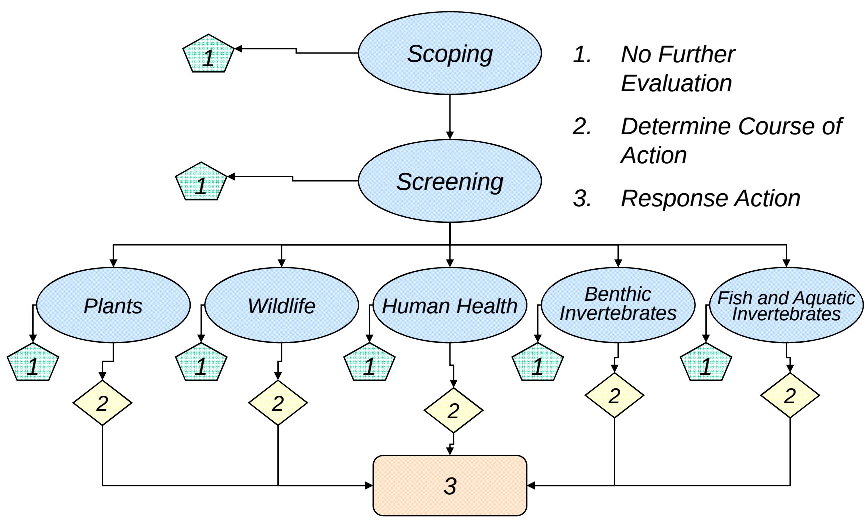
Specific Exposure Pathways



1. *No Further Evaluation*
2. *Determine Course of Action*
3. *Response Action*

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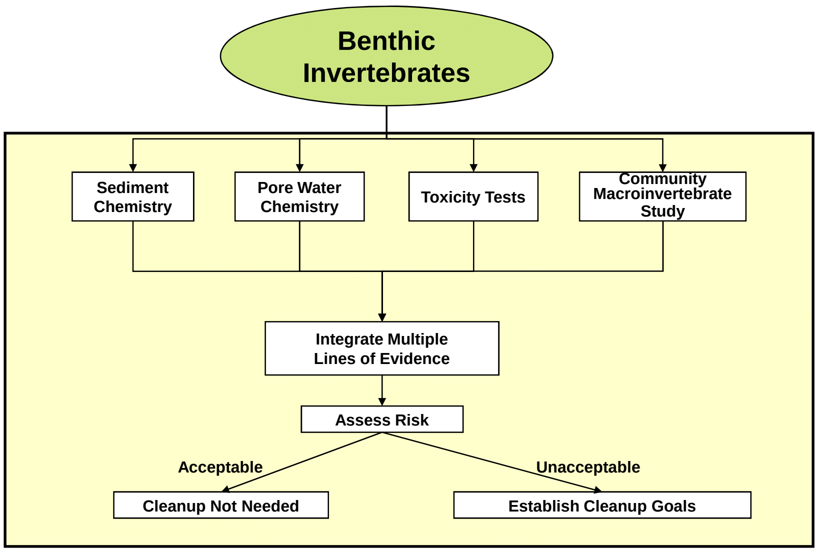
Benthic Pathway



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Procedures for Assessing Bioavailability to Benthic Invertebrates

- Sediment Quality Triad (SQT) approach:
  - Determine whether bulk sediment chemistry measures exceed SQGs or promulgated state standards
  - Carry out laboratory sediment toxicity tests using site-appropriate organisms and conditions
  - Conduct benthic macroinvertebrate surveys and compare to similar reference conditions
- Modifications to the SQT:
  - Replace bulk sediment chemistry with porewater measurements:
    - Indirect: compute contaminant bioavailability using spreadsheet models of partitioning (EqP) or sequestration (AVS/SEM)
    - Direct: *ex-situ* or *in-situ* measurement of porewater concentration
  - Augment toxicity testing through in-situ measurement of bioavailability from field-collected organisms
  - Infer bioavailability in laboratory bioaccumulation exposures

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Tools to Assess the Benthic Pathway
Chemical

- **Sediment**
  - Bulk Sediment
  - TOC/SOC
  - Acid Volatile Sulfide (AVS)
- **Porewater (Indirect)**
  - Peeper
  - Dialysis Bags
  - Diffusion Equilibration In Thin Films
  - Semipermeable Membrane Devices (SPME, POM, Polyethylene)
  - Gore module
  - Diffusive flux
  - Resuspension flux
  - Air Bridge
- **Porewater (Direct)**
  - Centrifugation
  - Suction Devices
  - Piezometers
  - Syringes
  - Trident probe
  - Ultraseep
  - Direct Porewater (EPA SW-846 8272/ ASTM D73-63-07)

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Tools to Assess the Benthic Pathway
Biological

- **Bioassays**
  - Bulk sediment, interstitial pore water, spiked sediment, elutriate, in situ bioassays
  - Mortality, growth, reproduction & behavior
- **Macroinvertebrate surveys**
  - Benthic Indexes (i.e., Benthic Response index, Index of Benthic integrity, etc)
  - River invertebrate prediction and classification system
  - Integration of benthic community categories
  - Rapid Bioassessment Protocol
  - Invertebrate indexes (i.e., Macroinvertebrate Aggregate or Bioassessment index)
  - Benthic infaunal abundance
- **Bioaccumulation studies**
  - Tissue Residue Analysis
  - Macroinvertebrate surveys

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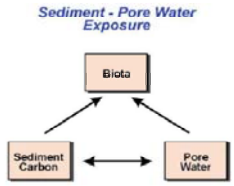
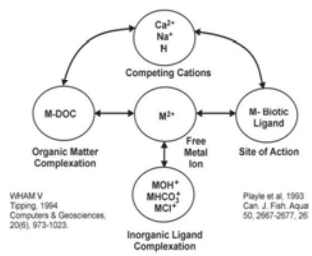
Tools to Assess the Benthic Pathway
Predictive

- Equilibrium Partitioning
- Narcosis Model
- AVS/SEM
- Biotic Ligand Model
- Toxicity Identification Evaluation



Equilibrium partitioning



Biotic Ligand Model

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Case Study Using the Benthic Pathway
Tectronix Wetlands Beaverton, OR

An NFA was determined for a stretch of Beaverton Creek in Oregon based on results from bulk sediment chemistry, toxicity testing, and AVS/SEM comparisons

- **Historic operations led to release of metals exceeding Oregon DEQ Level II screening level values for freshwater sediments**
- **Additional characterization of sediments conducted to assess bioavailability of sediment-associated metals and toxicity to benthic organisms**
  - **Surface sediment samples collected and analyzed for AVS/SEM, total metals, grain size, total solids, and TOC**
    - **maximum (SEM-AVS)/foc in any sediment sample was a factor of approximately 10 less than the EPA's adverse effect level**
  - **Toxicity tests with *Hyalella azteca* and *Chironomus dilutus* performed on subset of onsite and upstream surface sediment samples**
    - **Toxicity testing showed none of sediment samples had adverse effect on amphipods or midges based on the *H. azteca* mortality endpoint and *C. dilutus* growth endpoint**

Assessment concluded that surface sediment metals concentrations exceeding ODEQ Level II SLVs did not pose potential risks to the benthic community

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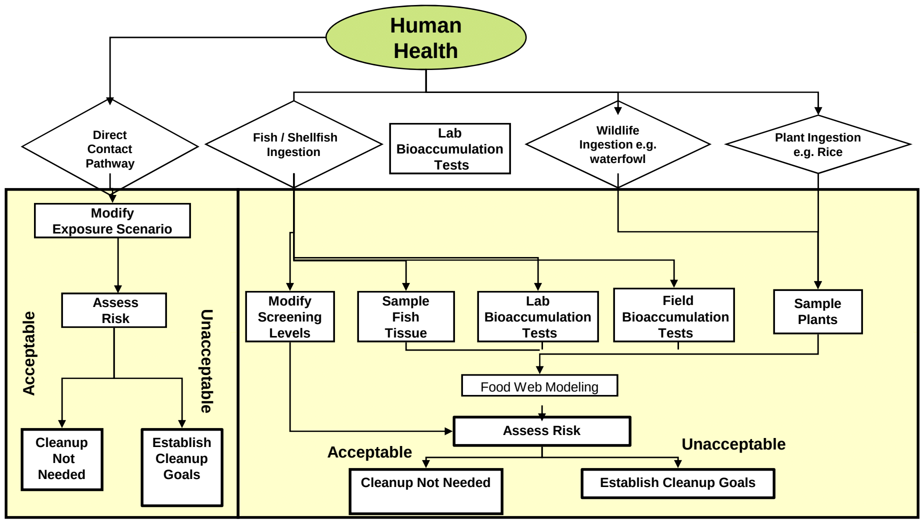
Human Health Pathway



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Tools to Assess the Human Health Pathway

- Direct Contact with Sediment
- Food Web Modeling
  - Fish consumption
  - Wildlife consumption
  - Plant consumption

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Case Study Using the Human Health Pathway – Johnson Lake

- Sediment in this 18 acre lake is contaminated with PCBs resulting from runoff from surrounding properties
  - Sediment samples indicated that PCBs were present at concentrations (57 to 1040 ppb) that exceeded screening levels (0.39 ppb) for protection of human health based on fish consumption
- Bioavailability utilized by collecting site specific fish tissue samples and calculating a site-specific biota sediment accumulation factor (BSAF)
  - BSAF used to calculate protective sediment concentration of PCBs
- Areas with highest PCB concentrations proposed for removal, reducing average sediment concentrations by 70%
  - Natural recovery mechanisms along with upland source control measures were expected to further reduce concentrations to protective levels over time

A specific cleanup number was not set: The area to be remediated was selected by removing sample locations from the risk calculations until an acceptable risk level was estimated ($1x10^{-5}$). The area to be cleaned up consists of the sample stations removed from the risk calculation

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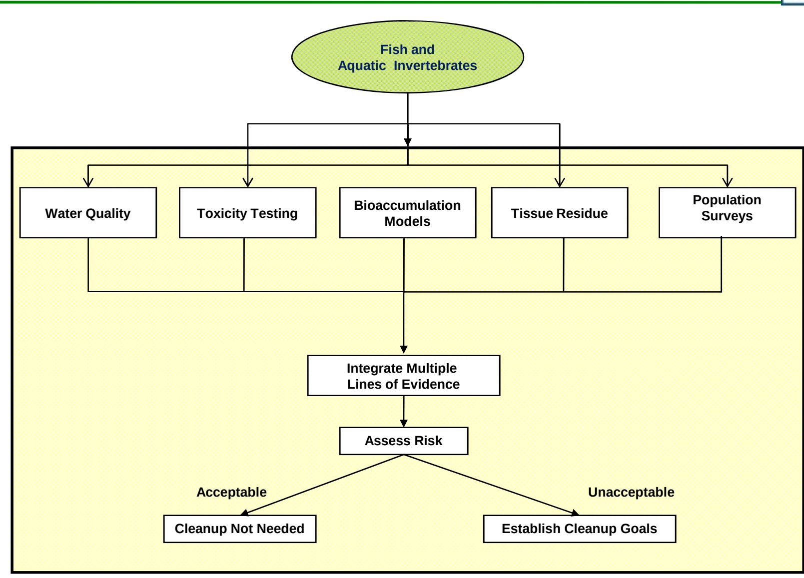
Fish and Aquatic Invertebrates Pathway



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Tools to Assess the Fish and Aquatic Invertebrates Pathway

- **Chemical**
  - Apply accumulation factors to measures of bulk sediment chemistry to estimate tissue residue concentrations, and compare to fish or amphibian tissue-based TRVs
  - Measure water quality above sediment bed and compare to AWQC or appropriate state standards
- **Biological**
  - Carry out laboratory sediment toxicity tests using site-appropriate organisms and conditions
  - Conduct population surveys and compare to similar reference conditions
  - Measure in situ bioavailability from field-collected organisms
- **Predictive**
  - Compute contaminant bioavailability using:
    - Accumulation Factors
      - Bioconcentration Factor
      - Bioaccumulations factor
      - Biota-Sediment Accumulation Factors
      - Biomagnification Factor
    - Food Web Models
    - Biotic Ligand Models

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Case Study Using the Fish and Aquatic Vertebrates Pathway

McCormick and Baxter Superfund Site, OR

- Fish and crayfish surveys were conducted at this former wood-treating facility on the shores of the Willamette River in Portland, OR
- Assess effects of residual creosote-derived contaminants including PAHs and dioxins
  - Assessment included sediment chemistry, bioassays, tissue residues in fish and crayfish, and fish histopathology
- Sediment chemistry and toxicity testing indicated substantial area of Willamette River sediments, proximal to the site, likely to be toxic
- By contrast, tissue residue values for PAHs in crayfish (*Pacifastacus leniusculus*) and large scale sucker (*Catastomus macrocheilus*) were low (PAH metabolites were not measured),
  - no evidence of statistical differences between site and upstream in the histopathology of the 249 fish livers examined

Based principally on sediment chemistry and bioassay data, as well as continuing NAPL discharges from sediments to Willamette River, the ROD required placement of an impermeable cap

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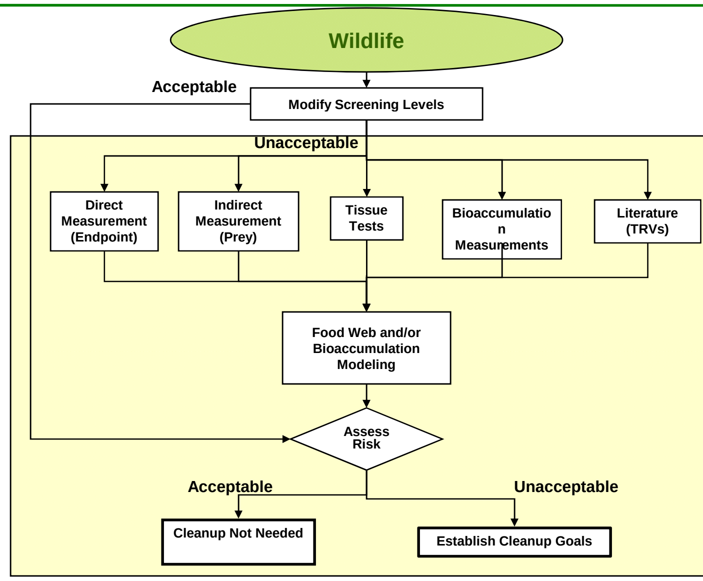
Wildlife Pathway



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Tools to Assess the Wildlife Pathway

- Direct Measurements
  - Population Surveys
  - Toxicity Testing
  - Tissue Residue Analysis
- Indirect Measures
  - Prey
- Food Web Modeling

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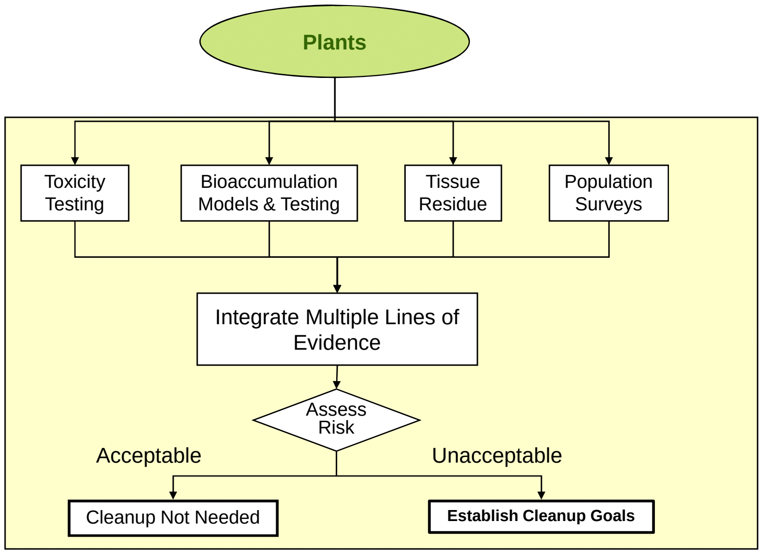
Plants Pathway



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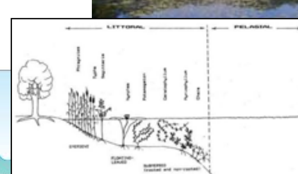
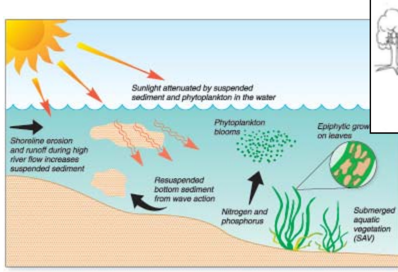
Tools to Assess the Plants Pathway

- Bioassay
- Bioaccumulation
- Plant Toxicity





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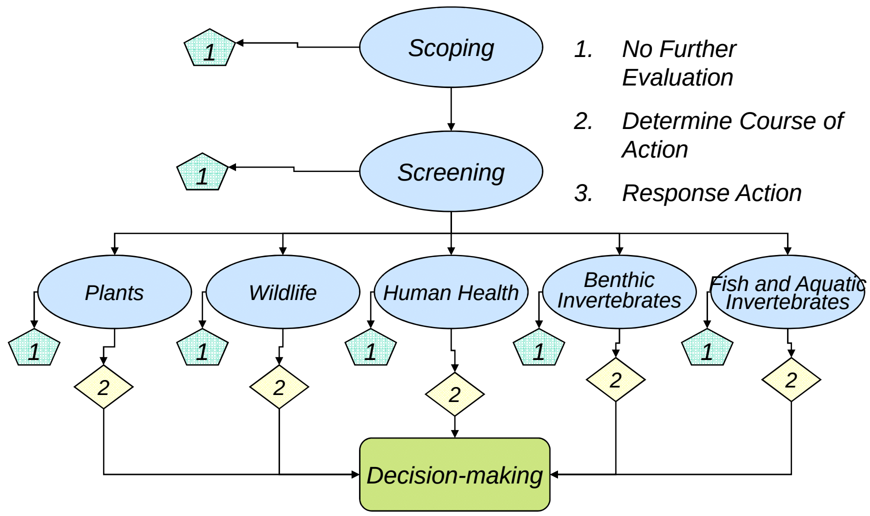
Using Bioavailability in Decision-making



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Case Study:
Mocks Pond Area Muncie, Indiana

- **Site History:**
  - **Abandoned limestone quarry received treatment sludge from galvanized (zinc-coated) wire product manufacturer**
  - **Lime added to neutralize the waste solutions before discharge, forming insoluble metal hydroxides.**
  - **"Sediment" was very fine iron-rich material with low TOC**
  - **COPC's were heavy metals (i.e., lead, zinc)**
  - **Pond bottom consisted of unconsolidated sediment devoid of organic material & bottom-dwelling insects**
  - **Testing suggested that deposited material were stabilized and not biologically available**

- **Potential Receptors:**
  - **Pelagic fish, snapping turtles, belted kingfishers, great blue herons, raccoon and potentially river otter**
  - **Limited human exposure with fence.**

CSM: Hypothesis that sludge-sediment would not support aquatic life and that metal hydroxides are not biologically available through dissociation in porewater or surface water

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Case Study:
Mocks Pond Area Muncie, Indiana

- Bioavailability was tested by measuring:
  - *in situ* porewater metal concentrations
  - surface water concentrations of metals
  - metals in the whole bodies and filets of pelagic fish species
  - Solubility of metals in sediment was determined by using novel large-volume "peepers"

Results of the exposure assessment

metals were tightly sequestered and not biologically available through porewater or surface water

metals in fish tissue were at levels that did not pose any significant consumption risk to recreational fishers

Peepers 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

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Case Study Questionnaire Response

- In 2008 a questionnaire was distributed to collect case studies where bioavailability was used at the site and determine if its use contributed to the development of site cleanup levels
- Bioavailability was used during the assessment of 37 out of 39 case studies collected
  - 8 case studies (approximately ¼ of studies received) where bioavailability helped in setting cleanup goal
  - Bioavailability was assessed at most sites but not used to develop the cleanup goals
  - Several of the case studies reported that cleanup goals had not been calculated
- Question: Not sure if the environmental community understands how to use bioavailability in decision-making

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Thank You

- Document Status:
  - Currently DRAFT
  - Published and public offering of Free Internet-based Training January 2010
- Links to Team resources at:
  - http://www.itrcweb.org/teampublic_CS.asp
- Question and Answers!

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