Ecological Risk Assessment

MassDEP ORS

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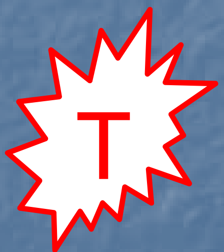
Overview

1. Initial Assessment
2. Stage I Ecological Screening
3. Stage II Ecological Risk Characterization
4. Substantial Hazard Evaluation
5. Sediment Risk Example
6. Equilibrium Partitioning (EqP)

Ecological Risk Characterization Method 3



= Technical Update

http://www.mass.gov/dep/service/compliance/riskasmt.htm

= Problem area

Method 3

Method 3 is always an option.

- Should be used if:
  - There are COCs in sediment or surface water.
  - There are Bioaccumulating COCs.
  - Neither Method 1 or 2 can be used.

Ecological Risk Assessment: Process Overview

Initial Assessment

Imminent Hazard

Readily Apparent Harm

Stage I screening

Stage I Screening

Does site qualify for any size/habitat quality exemptions?

Concentrations consistent w/background or local conditions?

Do concentrations exceed screening criteria?

Stage II Risk Characterization

Stage II Risk Characterization

Problem Formulation
Conceptual Site Model
Assessment Endpoints

Risk Analysis
Exposure & effects assessment

Risk Characterization

Significant Risk?

Initial Assessment

Main Question: Is it clear w/o a quantitative risk assessment that something must be done?

↓

Imminent Hazard

↓

Readily Apparent Harm

↓

Stage I screening

Imminent Hazard
(310 CMR 40.0950)

- Evidence of stressed biota including fish kills or abiotic conditions.
- A release which produces immediate or acute adverse impacts.
- Requires Immediate Response Action.

Readily Apparent Harm
(310 CMR 40.0995)

- Visible evidence of sheens or NAPL.
- Visible evidence of stressed biota (e.g., fish kill).
- OHM exceeds surface water standards (NRWQC).
- Visible presence of oil, tar, NAPL in soil within 3' of surface.


FLOCCULENT = READILY APPARENT HARM


FLOCCULENT = READILY APPARENT HARM

Stage I
Ecological Screening

Stage I Screening

Main Question: Are there any potentially significant exposures?

↓

Does site qualify for any size/habitat quality exemptions?

↓

Concentrations consistent w/background or local conditions?

↓

Do concentrations exceed screening criteria?

↓

Stage II Risk Characterization

Stage I Screening

No significant risk

Stage I Screening

Determine the need for Stage II

Risk is obvious

Stage I Screening Outcomes

- Stage II is not required
  - There are no potentially significant exposures/NSR
  - Significant Risk present
- Stage II is required:
  - Because it's not clear if a condition of NSR exists

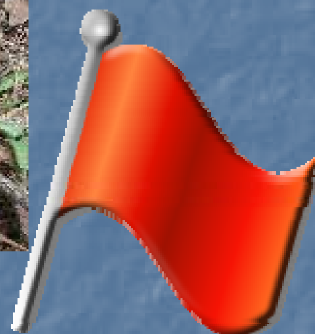
Stage I

1. Habitat Quality Assessment

– *is the area a viable habitat?*

If Endangered, Threatened or species of Special Concern are present, you have a viable habitat

Braun's Holly fern- E



Northern Harrier - T

Blue-Spotted Salamander-SC

Eastern Box Turtle-SC

Terrestrial Habitat Quality

- Undeveloped area < 2 acres
  - Exempt
- Undeveloped area 2 - 6 acres
  - Depends; site specific
- Undeveloped area > 6 acres
  - Not exempt
- ACECs & areas with Threatened or Endangered Species, or Species of Special Concern
  - Exemptions Do NOT apply

Man-Made Water Bodies

Factors to Consider:

- Aquatic life
- Bottom substrate
- Habitat value
- Area land use
- Management practices
- Hydraulic regime
- Size

Size Exemption - Lakes & Ponds

- Sediment contamination may be eliminated from the risk assessment if the entire extent of the sediment contamination is:
- < 1000 s.f., and
- < 10% of a small pond or
- < 10% of any ecological resource area (for example, 10% of the littoral zone) in a large pond or lake

Size Exemption – Rivers & Streams

- Sediment contamination may be eliminated from the risk assessment if the entire extent of the sediment contamination is less than 1000 s.f., and
- Does not extend more than 50% of the width of the river or stream, and
- Does not extend more than 500 linear feet along the length of the river or stream.

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Stage I

2. Comparison to Background or Local Conditions

Background

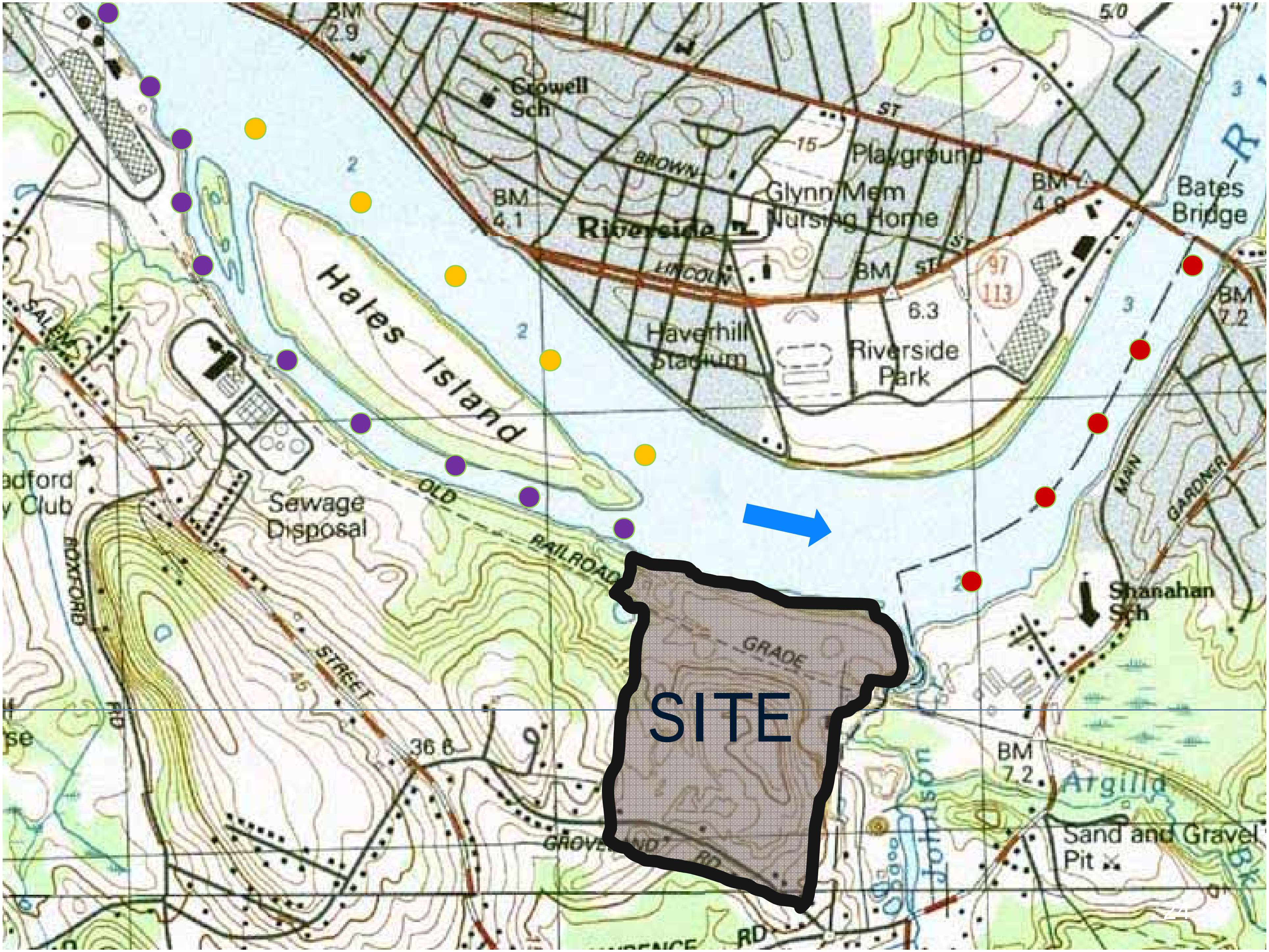
- Background reference location:
  - Should have similar physical and habitat conditions
  - Should be as close as possible w/o being impacted by site and in the same watershed
  - Sufficient sample size needed to compare site and reference area ($\geq$8 to compare statistically)

Background concentrations of OHM = NSR (310 CMR 40.1020)

Local Conditions

(an extension of background in sediment & S.W.)

- COCs higher than background, but ubiquitous near the site due to sources other than the site
- Contaminants from permitted discharges, non-point sources and other disposal sites
- Must be assessed on a chemical specific basis



SITE
Hales Island
Riverside
Crowell Sch
Playground
Glynn Mem Nursing Home
Haverhill Stadium
Riverside Park
Bates Bridge
Sewage Disposal
Shanahan Sch
Sand and Gravel Pit
Argilla
Johnson
OLD RAILROAD GRADE
GROVELAND RD
SALEM STREET
BOXFORD RD
BROWN
LINCOLN ST
MAIN
GARDNER
BM 2.9
BM 4.1
BM 4.8
BM 7.2
6.3
36.8

Stage I

3. Comparison to Screening Benchmarks

Benchmarks

- Sediment:
  - Probable Effects Concentrations (PECs)
  - Threshold Effects Concentrations (TECs)
- Surface Water:
  - Massachusetts Surface Water Quality Standards (314 CMR 5.00)
    - Standards based on USEPA National Recommended Water Quality Criteria (NRWQC)

Sediment Benchmarks

- Consensus-based guidelines developed by MacDonald et al.(2000)

- If the COC concentration is > PEC or TEC for any COC, a Stage II Risk Characterization must be done.

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Sediment Benchmarks

- Probable Effects Concentrations (PECs)
  - Concentrations above which adverse effects are expected to occur more often than not
  - Used for all metals except mercury
- Threshold Effects Concentrations (TECs)
  - Concentration below which adverse effects are not expected to occur
  - Used for PAHs, PCBs, & mercury

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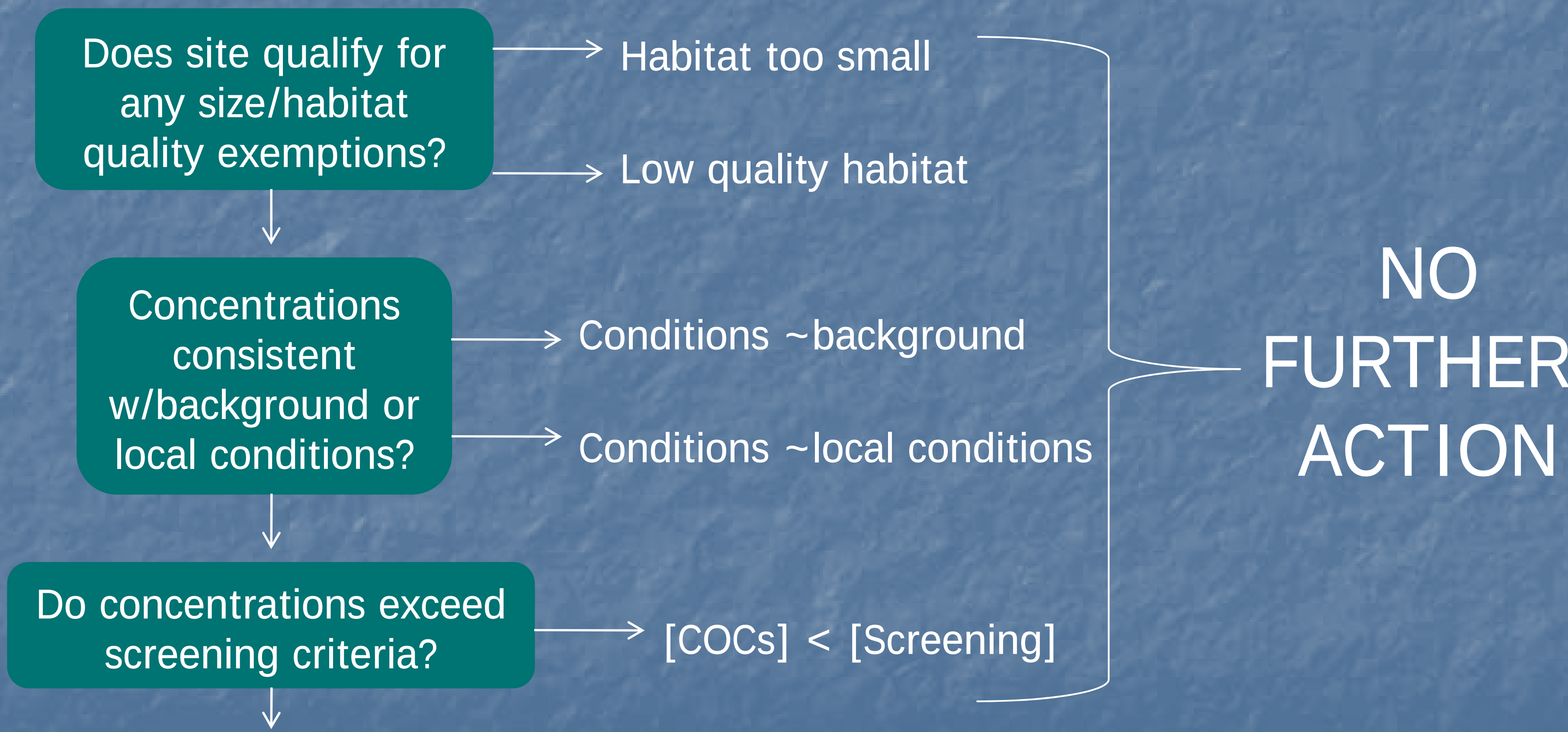
Surface Water Benchmark Derivations

- USEPA National Recommended Water Quality Criteria (NRWQC)
  - Chronic value should be used when available
  - Sheens from OHM on surface waters are considered an exceedance of the Surface Water Quality Regulations and constitute Readily Apparent Harm

Stage I Environmental Screening

Main Question: Are there any potentially significant exposures?



Stage II Risk Characterization

Stage II
Ecological Risk Characterization

Is an Ecological Risk Assessor involved?

Stage II Ecological Risk Characterization

Main Question: Is there significant risk at the site?

Problem Formulation
Conceptual Site Model
Assessment Endpoints

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Risk Analysis
Exposure & effects assessment

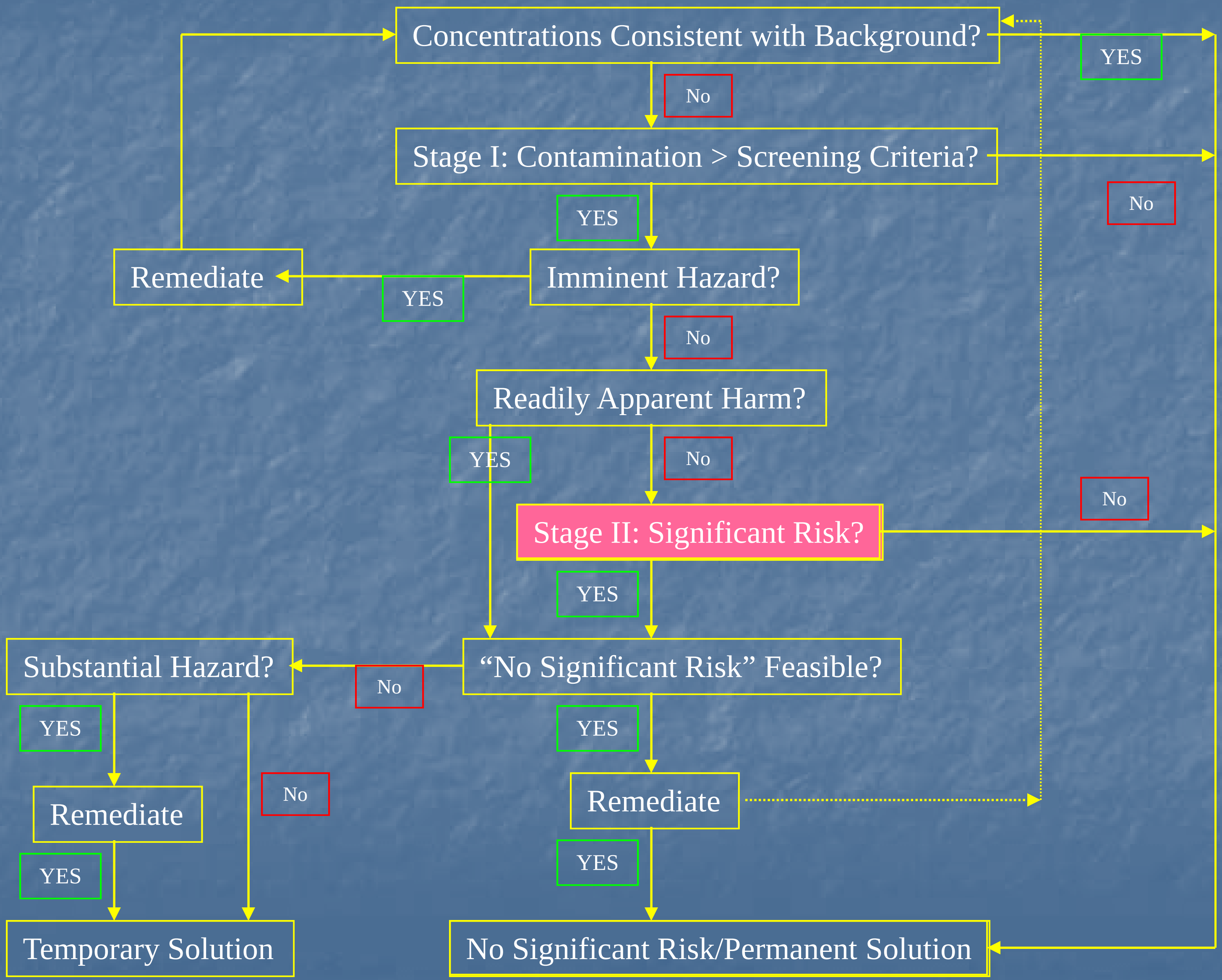
↓

Risk Characterization

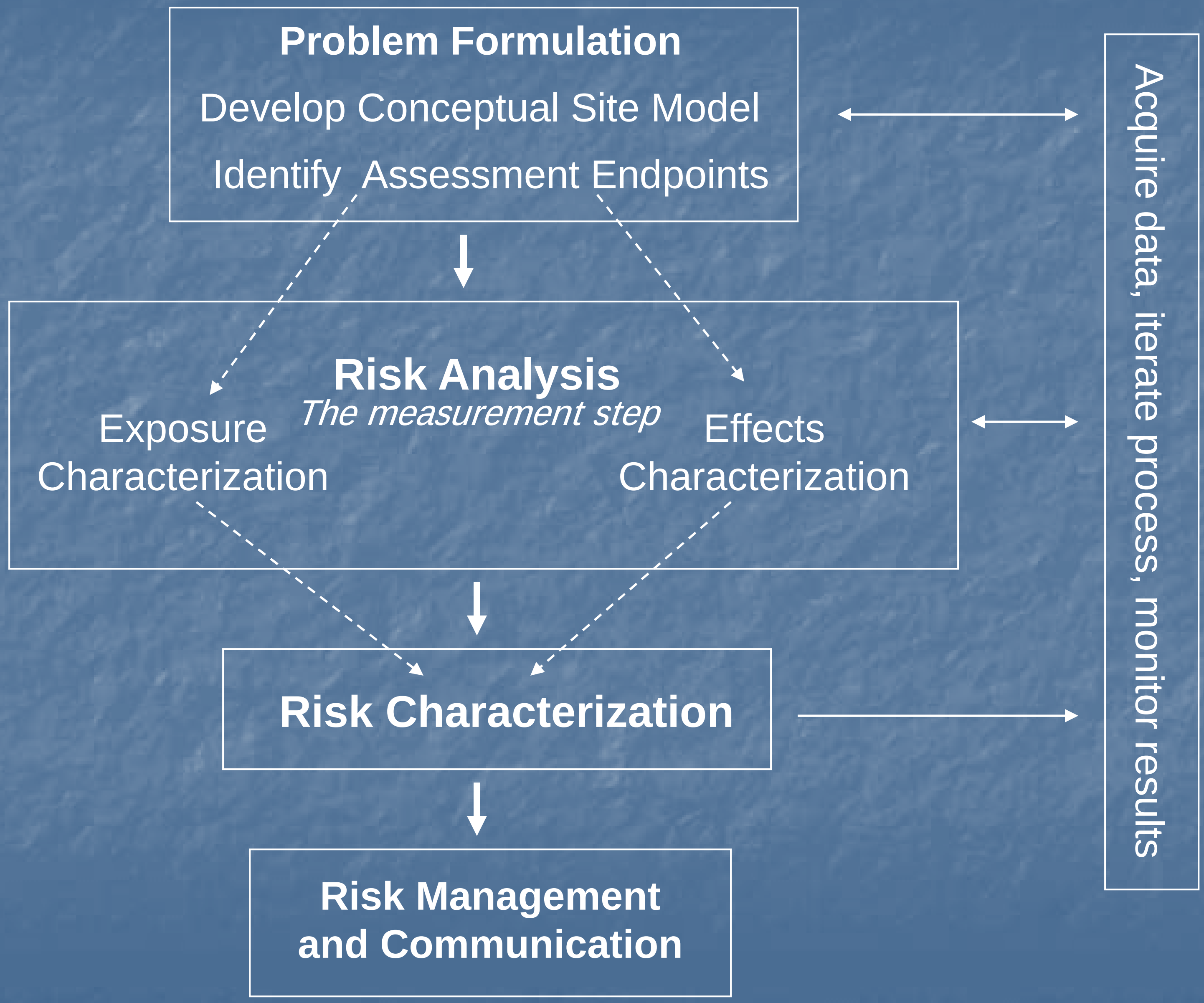
↓

Significant Risk?

Ecological Risk Assessment
Decision Diagram for Contaminated Sediment



Ecological Risk Assessment Framework



Stage II
Problem Formulation

"A problem well defined is a problem half solved."
– *John Dewey*

Problem Formulation

- Identify the ecological resources you want to assess to determine if there is an ecological impact.
- What species should be the focus of the ecological risk assessment?
- Develop Conceptual Site Model (CSM)

Stage II
Problem Formulation
Developing Conceptual Site Model

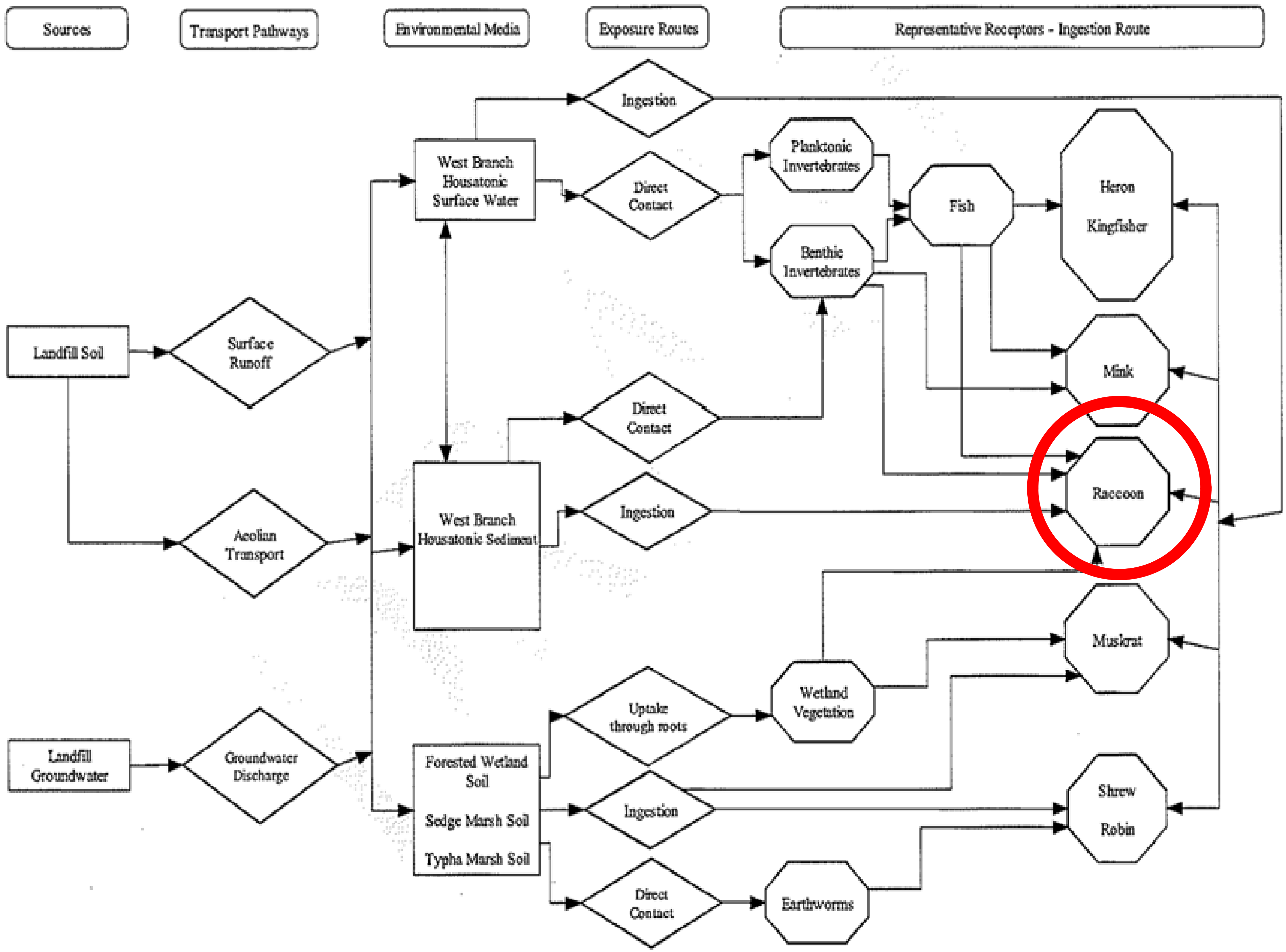
Conceptual Site Model :

A visual and/or narrative representation of the links between:

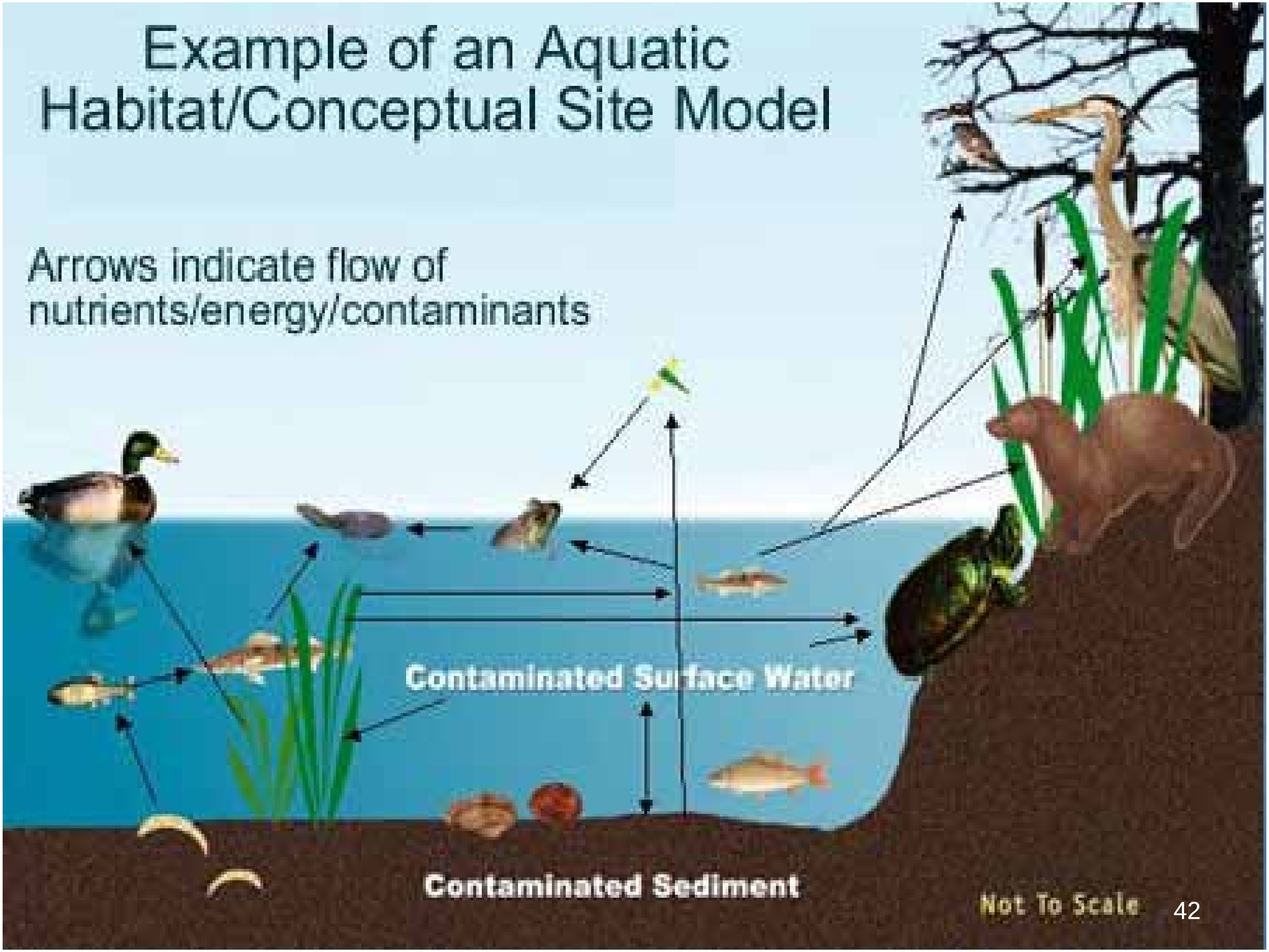
- Contaminants & Sources
- Fate & Transport of COCs
- Receptors
- Exposure Pathways

A good CSM can help...

- The risk assessor ask questions pertinent to the site.
- Guide data collection.
- Inform the exposure assessment.
- Put data into context to better characterize risk.



Sources
Transport Pathways
Environmental Media
Exposure Routes
Representative Receptors - Ingestion Route
Landfill Soil
Surface Runoff
Aeolian Transport
Landfill Groundwater
Groundwater Discharge
West Branch Housatonic Surface Water
West Branch Housatonic Sediment
Forested Wetland Soil
Sedge Marsh Soil
Typha Marsh Soil
Ingestion
Direct Contact
Direct Contact
Ingestion
Uptake through roots
Ingestion
Direct Contact
Planktonic Invertebrates
Benthic Invertebrates
Fish
Wetland Vegetation
Earthworms
Heron
Kingfisher
Mink
Raccoon
Muskrat
Shrew
Robin


Example of an Aquatic
Habitat/Conceptual Site Model
Arrows indicate flow of
nutrients/energy/contaminants
Contaminated Surface Water
Contaminated Sediment
Not To Scale
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Developing CSM

- CSMs are an iterative tool
- Site Reconnaissance is critical
- Should include all COCs, sources, routes of exposure and receptors that could be of concern
- Pathways should only be eliminated if there is high confidence that pathway is incomplete

Conceptual Site Models – Common Problems

- The most common problem with CSMs is that they are not done or not integrated into the process.
- Exposure pathways ignored or overlooked.
- CSMs that do not incorporate how chemicals were applied often overlook important fate and transport mechanisms.

Stage II
Problem Formulation
Identify Assessment Endpoints

Assessment Endpoints

- Assessment endpoint – effects on an organism(s) that can be measured.
- Example: Survival, growth & reproduction of Largemouth Bass

Selecting Assessment Endpoint Species

Assessment Endpoints should:

- Be sensitive to OHM present
- Represent the most susceptible feeding strategy
- Provide key ecological functions, or represent a group that does
- Be measureable

Challenges of Assessment Endpoint Selection

- Large number of exposed species in most habitats.
- Limited data on natural history and exposure pathways.
- Endpoint selection is often “tool driven”.

Amphibians often not assessed

Mudpuppy
Jefferson Salamander
Blue-spotted Salamander
Spotted Salamander
Marbled Salamander
Eastern Newt
Northern Dusky Salamander
Eastern Red-backed Salamander
Four-toed Salamander
Northern Two-lined Salamander
Eastern Spadefoot
American Toad
Fowler's Toad
Spring Peeper
Gray Treefrog
American Bullfrog
Green Frog
Pickerel Frog
Northern Leopard Frog
Wood Frog

Assessment Endpoint?

Assessment Endpoint Examples

- Site with widespread PCB releases:
  - Survival and reproduction of piscivorous mammal (Mink)

- Site with localized metal releases:
  - Survival and reproduction of insectivorous bird (swallows)

Stage II
Risk Analysis
Exposure Characterization & Effects Characterization

Risk Analysis

- Evaluate measurement endpoints
- Collect & Integrate information:
  - Toxicity
  - Concentrations
  - Spatial distribution of COCs
  - Exposures
  - Observations

Stage II
Risk Characterization

Risk Characterization

- Evaluate all the available data to determine if it supports a conclusion of no significant risk for each assessment endpoint.
- More than one measurement endpoint?
  - Weight of evidence approach
  - Lines of evidence

Three Lines of Evidence in a Sediment Risk Assessment

3 Lines of Evidence

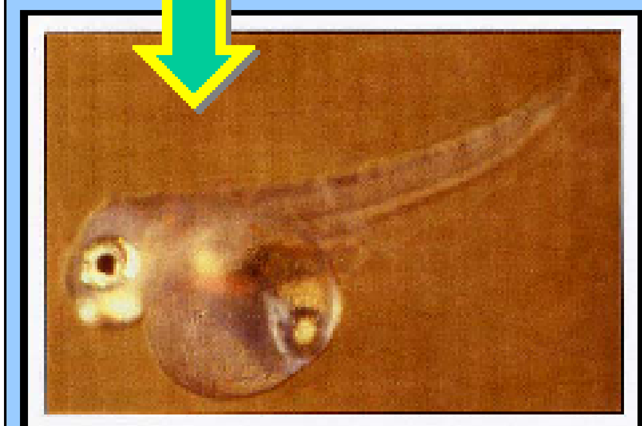
Consider Three Lines of Evidence

- Chemistry (literature review) → Assess frequency and magnitude of exceedance
- Toxicity (Phase I and Phase II) → Comparison to Effects Thresholds
- Biological Surveys (Community Assessment) → Qualitative Assessment

Classify Risks as High, Intermediate, or Low in PSA

Extrapolate Findings to Other Species and Downstream

- Survival
- Growth
- Reproduction
- Malformations



Weight of Evidence

When comparing 2 or more measurement endpoints be aware that not all measurement endpoints are created equal

After the Risk Assessment Substantial Hazard

- If risk is significant but a permanent solution is not feasible, then a Substantial Hazard Evaluation (40.0956) must be completed.
- By definition a temporary solution must eliminate any Substantial Hazards.

To achieve Condition of No Substantial Hazard to the Environment:

- Steps must be taken to eliminate or mitigate:
  - Evidence of stressed biota;
  - OHM within 3 feet of the soil surface or within 1 foot of sediment surface;
  - Continuing discharge of contaminated groundwater to surface water or sediment;
  - Migration of OHM to additional environmental media.

ECOLOGICAL RISK CHARACTERIZATION-SEDIMENT EXAMPLE

ASSESSMENT ENDPOINTS - BENTHIC INVERTEBRATE EXAMPLE

Benthic Macroinvertebrates <u>Must</u> Be Evaluated In Addition To Other Appropriate Receptors

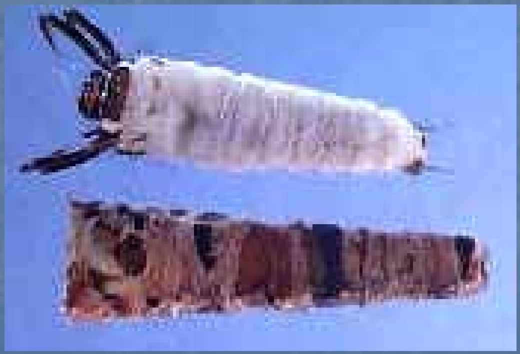
Amphipod (scud)

Isopods (aquatic sowbugs)

Decopod (crayfish)

Molluscs (snails)

Ephemoptera (mayfly)



Trichoptera (caddisfly)

Benthic Invertebrate Assessment Endpoints

- Survival, growth and reproduction
  - Should be evaluated in all cases
- Community Condition
  - Can provide supporting information

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MEASURES OF EFFECTS - SEDIMENT EXAMPLE

Measurements of Effects

1. Benchmarks - generally conservative, should be included as a point of reference.
2. Toxicity testing – ORS considers this the most reliable measure.
3. Benthic Community Survey – useful but expensive if done right.

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Measures of Effects in Relation to Assessment Endpoints

- Survival, Growth & Reproduction
  - Benchmarks
  - Sediment toxicity testing
- Community Assessment
  - Benthic community field surveys

1. SEDIMENT BENCHMARKS - SEDIMENT EXAMPLE

Published sediment concentrations based on large empirical data sets

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Sediment Benchmark Selection

- Values published by government agencies preferred
  - e.g., Threshold Effects Level (TEL)
  - NOAA SQuiRTs – a good resource
    - http://response.restoration.noaa.gov/book_shelf/122_NEW-SQuiRTs.pdf
- Other options require more justification:
  - Single study benchmarks
  - Benchmarks derived using equilibrium partitioning calculations
  - Site-specific derived benchmark

Benchmark Red Flags

- No benchmarks
- The use of non-agency published benchmarks with no supporting documentation.
- Large exceedances not flagged as significant risk.
- “Cherry Picking” the highest benchmark values.

2. SEDIMENT TOXICITY TESTING - SEDIMENT EXAMPLE

This is where we take a bunch of sediment from the field into the lab and expose test organisms to the sediment for a period of time under pre-defined laboratory conditions.

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Chironomus tentans - Insect

- USEPA Test Method 100.5 *Chironomus tentans* life cycle test for survival, growth, reproduction & development

Hyalella azteca - amphipod

USEPA Test Method 100.4 *Hyalella azteca* 42-day chronic tests for survival, growth, and reproduction

Sediment Toxicity Testing

- Direct method for assessing toxicity of sediment to benthic invertebrates.
- Test Length:
  - Short-term: Not Recommended
    - e.g., 10-day survival test with chironomid
  - Medium-term: Recommended
    - e.g., 28-day growth test with Hyallela
  - Longer-term: Recommended
    - e.g., 42-day reproduction test with Hyallela

Looking at Sediment Toxicity Test Results

28-Day amphipod test at coal tar site:

- Four reference samples:
  - 68%, 73%, 73%, and 90% survival
- Six Site Samples
  - Two site samples with no statistically significant difference:
    - 43% and 58% survival
  - Four site samples with a statistically significant difference:
    - 0%, 0%, 0%, and 10% survival

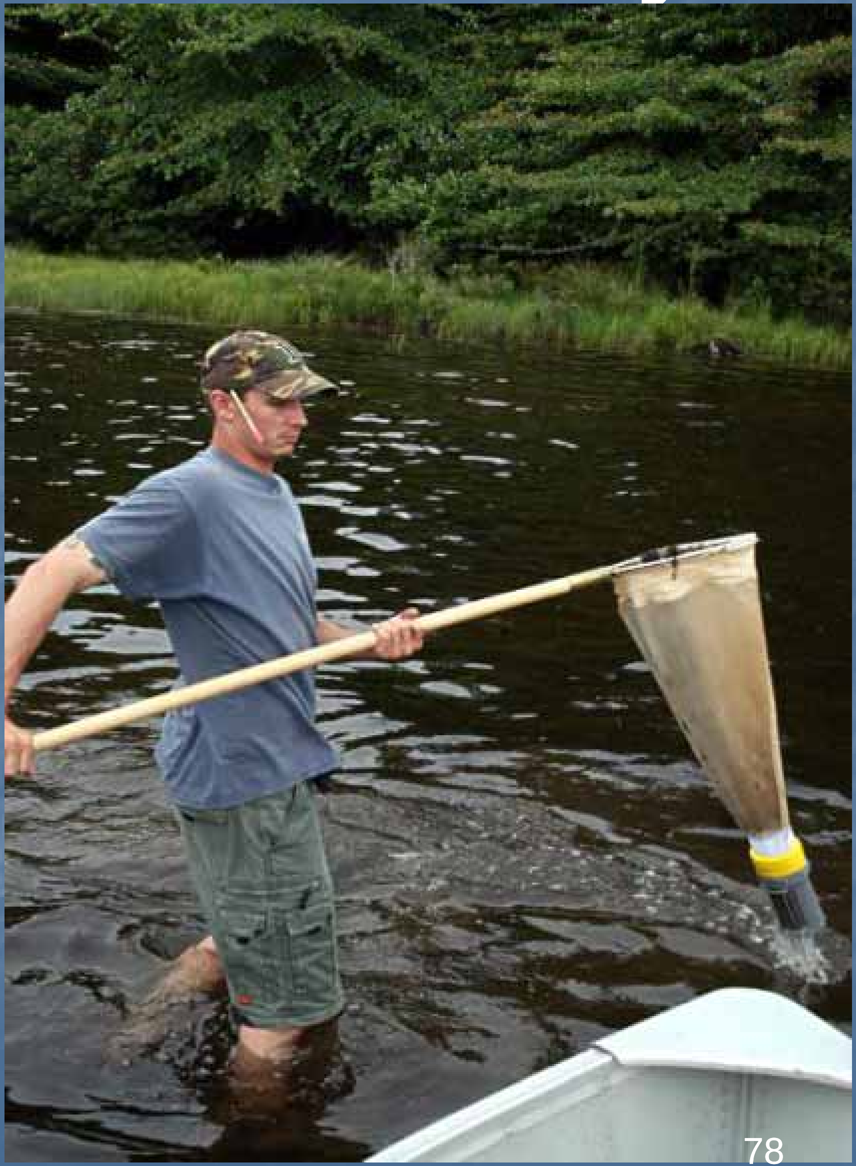
Sediment Toxicity Testing Red Flags

- High toxicity in reference samples can complicate comparison between site toxicity and reference toxicity.
- 10-day tests used instead of longer tests.
  - Less expensive but less sensitive
- Reproductive endpoint is often skipped, increasing uncertainty about risk.
- Small sample size increases uncertainty.

3. BENTHIC COMMUNITY SURVEYS - SEDIMENT EXAMPLE

Benthic Invertebrate Surveys

- Evaluate invertebrate community structure
- Collect samples from contaminated areas and reference areas
- Sieve samples
- Submit to lab for identification



Benthic Invertebrate Surveys

- Samples are compared using abundance and diversity measures
- Site samples are compared to reference areas

Benthic Invertebrate Survey Example

BENTHIC MACROINVERTEBRATE SURVEY														
					STATION									
					Reference Area									
			Feeding Group		Hells 1/2 Acre			Greenough Blvd				Property 20		
TAXON				HBI	ref1	ref2	ref3	ref4	ref5	ref6	AVE	sd-14	sd-15	AVE
ANNELIDA	OLIGOCHAETA	ENCHYTRAEIDAE	GC	10								4	2	
ANNELIDA	OLIGOCHAETA	TUBIFICAIDAE	GC	10								38	272	
ANNELIDA	OLIGOCHAETA	NAIDIDAE	GC	9									2	
BIVALVA		BIVALVA	FC										80	
BIVALVA	VENEROIDA	SPHAERIIDAE	FC	8								40	54	
GASTROPODA	BASOMMATOPHORA	PHYSIDAE	GC	8				1		1		16		
GASTROPODA	BASOMMATOPHORA	PHYSA SP.	GC						1			2		
INSECTA	COLLEMBOLA	COLLEMBOLA	GC							1				
INSECTA	DIPTERA	CHIRONOMIDAE	GC	8	2	14	3			3		76	10	
INSECTA	TIPULOIDEA	TIPULIDAE	SH										2	
NEMATODA		NEMATODA	PA									6	4	
Total Abundance:					2	14	3	1	1	5	**4.3**	182	426	**304**
Total Number of Taxa:					1	1	1	1	1	3		7	8	
Number of Discrete Taxa:					1	1	1	1	1	2		6	7	

Feeding Group:

GC = gatherer/collector

FC = filterer/collector

PR = predator

SH = shredder

PA = parasite

HBI = Hilsenhoff Biotic Index; Measure of Tolerance/Intolerance (1 = low tolerance; 10 = high tolerance)

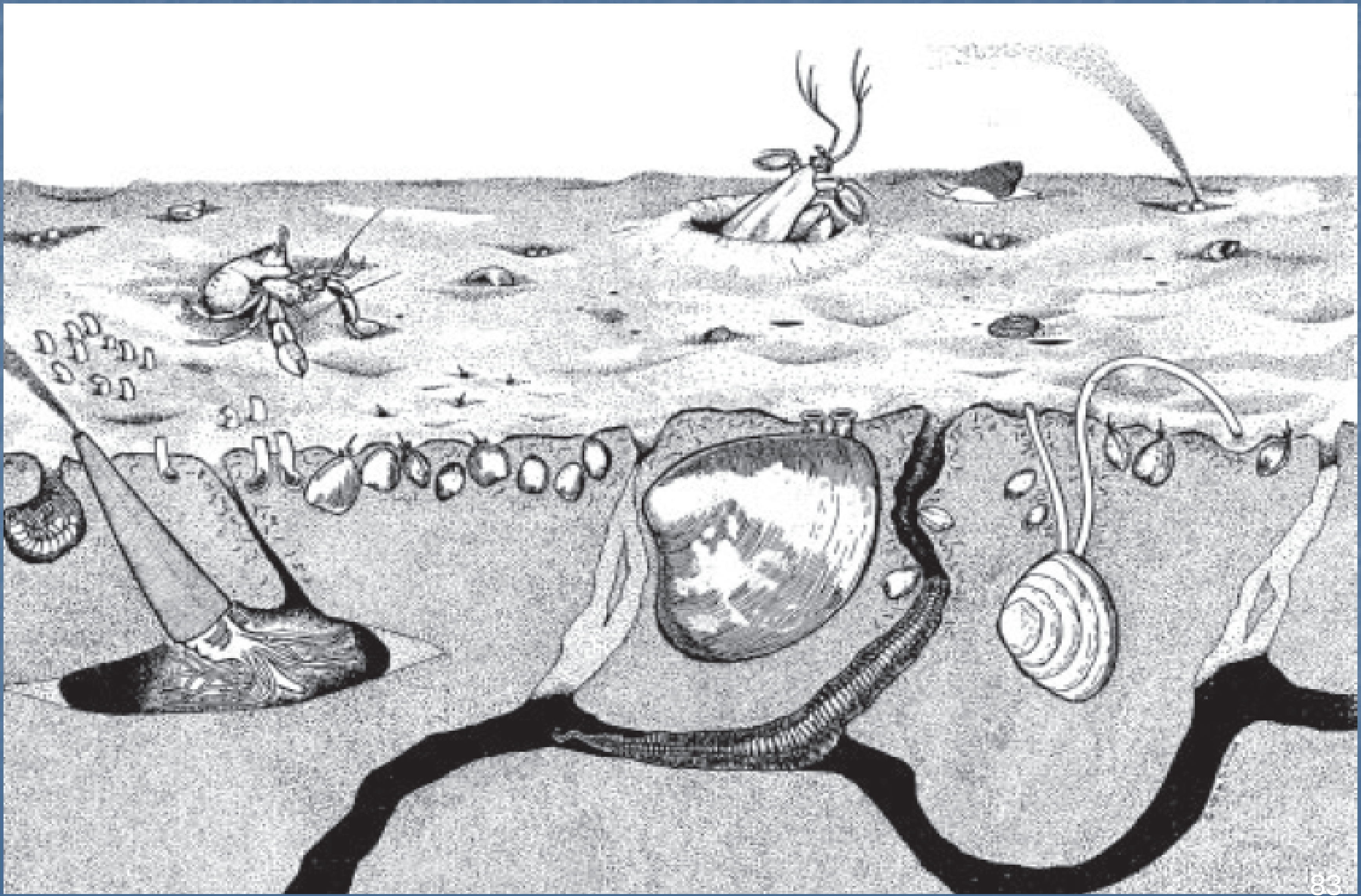
Benthic Invertebrate Surveys Red Flags

- Few samples saves money but increases uncertainty.
- Inappropriate reference area selection.
- Reference area impacted by other stressors or habitat quality not equivalent to site.

Risk Characterization Recommendations

- Consider 3 measures of effect:
  - Benchmarks, toxicity tests, community surveys
- At a minimum, benchmarks and toxicity tests should be included
- Toxicity tests are generally:
  - More accurate than benchmark comparisons
  - More conclusive than benthic invertebrate surveys

Equilibrium Partitioning-Based Approaches for Sediment Assessment



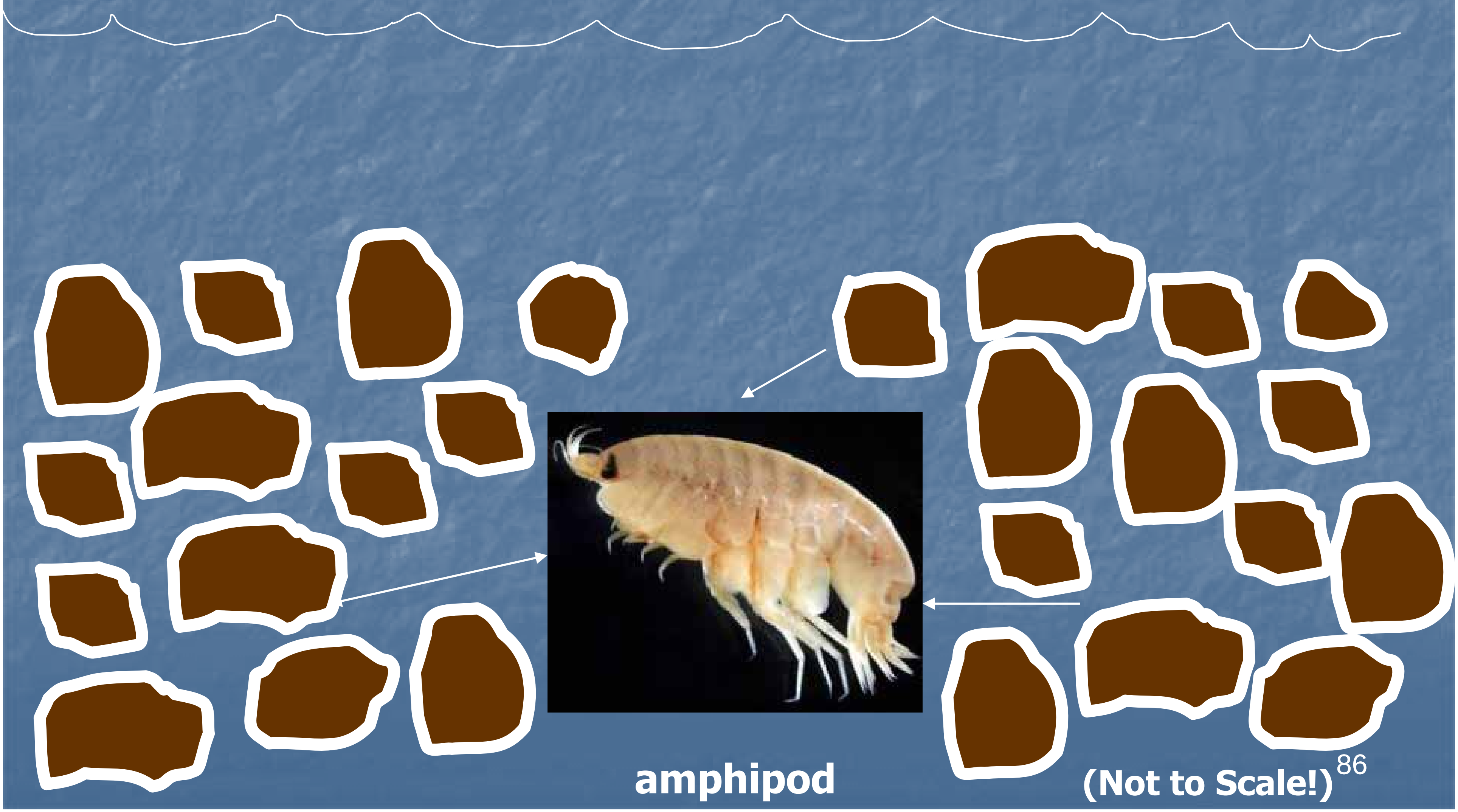
Emerging Technical Issues Related to Equilibrium Partitioning (EqP)

- Underlying Theory
- AVS/SEM to Evaluate Metals in Sediment
- Evaluation of Petroleum Contamination
- Protection of Sediment-Ingesting Benthic Organisms
- Passive Samplers

Why Does This Matter?

- **EqP is increasingly used for eco risk assessments.**
- **Ecological risk/harm may be underestimated if underlying assumptions are not valid.**
- **LSPs need to recognize when:**
  - **Approach may not be valid**
  - **Interpretation of results may not be valid**

Benthic Invertebrate Exposures to Pore Water



General EqP Assumptions

- Exposure and toxicity are determined by the pore water concentration
- Pore water concentration is determined by:
  - the bulk sediment concentration
  - the percent of organic carbon in sediment
  - the affinity of the contaminant for organic carbon

Basic EqP Equation

$C_{sed} = f_{oc} \times K_{oc} \times C_w$

Where:

Csed	=	sediment concentration
foc	=	fraction organic carbon
Koc	=	organic carbon:water partition coefficient
Cw	=	pore water concentration

USEPA (2003) ESB Approach

Equilibrium Partitioning and Acid Volatile Sulfide-Simultaneously Extracted Metals

USEPA 2005 EPA-600-R-02-011

AVS-SEM Theory

- Divalent metals (cadmium, copper, lead, nickel, silver, and zinc) are bound to sulfide minerals, reducing bioavailability
- When:
  - Metals < AVS, no risk, or
    - $\Sigma_i[SEM_i] < [AVS]$
  - Metals < Water Toxicity Values, no risk
    - $\Sigma_i [M_{i,d}]/FCV_{i,d} < 1$

AVS-SEM
General Cautions

- Conditions change over time and space
- Measurements include non-metal binding sulfide
- Based on acute rather than chronic effects
- Does not consider bioaccumulation
- Only evaluates six metals

Interlaboratory Variability in AVS-SEM Measurements

A study compared analysis from seven laboratories:

- For the same samples, AVS varied by a factor of 10-1000 for each of four study sediments.
- SEM varied a factor of 20-50 among the labs for each of the four samples.

AVS/SEM: ORS Conclusions

- **AVS/SEM should be confirmatory evidence, and should not be used to overrule lines of evidence.**
- **AVS/SEM data are given a low priority for collection, low weight in weight of evidence.**

EqP-derived PAH sediment benchmarks as Indicators of Petroleum Toxicity

PAHs and Petroleum Toxicity

- Using EqP, the toxicity of petroleum has been attributed to PAHs, but recent EPA research suggests:
  - Toxicity may occur with weathered oils with low PAH content (e.g., lubricating oils)
  - Assessing toxicity of low PAH oils based on PAH concentrations will greatly underestimate toxicity
- EPA PAH EqP benchmarks do not account for other petroleum components

Physical Effects of Non-PAH Petroleum Components

- Smothering
- Impaired movement and feeding
- Habitat destruction
- Reduction in the sediment aerobic layer
- Increased organic enrichment

Readily Apparent Harm (MCP Approach to Petroleum Hydrocarbon Physical Effects)

- The MCP defines visible presence of oil or tar over greater than 1000 square feet within one foot of the sediment surface as significant risk

  (310 CMR 40.0995(3)(b))
- This accounts for risks from physical effects of petroleum

Sediment Ingesters and Organic Chemicals

EqP Theory May Not Address Sediment Ingesters

- Freshwater sediment ingesters can constitute most of the benthic community.
- Rates of sediment ingestion can be greater than 100 times body weight per day
- If sediment ingestion drives exposure, EqP is not protective
- For contaminants with log Kow>5, sediment ingestion drives exposure

juvenile chironomus

Lumbriculus

Method 1 Organic Chemicals With Log Kow > 5

- 8 of the 16 PAHs
- Pesticides such as DDD, DDE, DDT, and Methoxychlor
- Hexachlorobenzene
- Pentachlorophenol
- Phthalates
- PCBs
- 2,3,7,8-TCDD

Petroleum Take-Home Messages

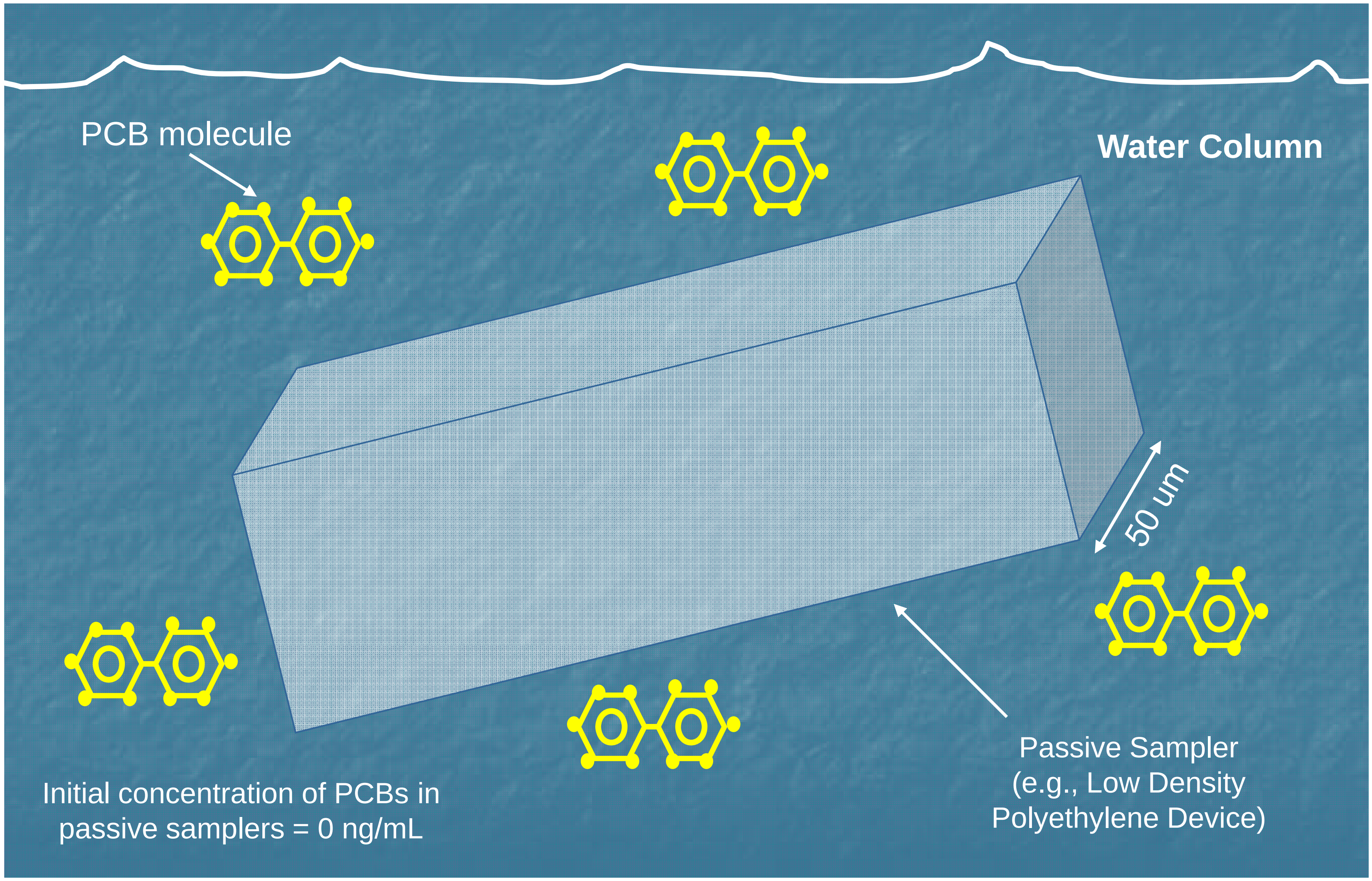
- EqP does not protect sediment ingesters when high Kow PAHs are present.
- EqP does not consider the toxicity of non-PAH components of petroleum.
- EqP is only a single line of evidence.
- Use EqP approaches for petroleum with caution.

EqP and Passive Samplers

Sediment Passive Samplers

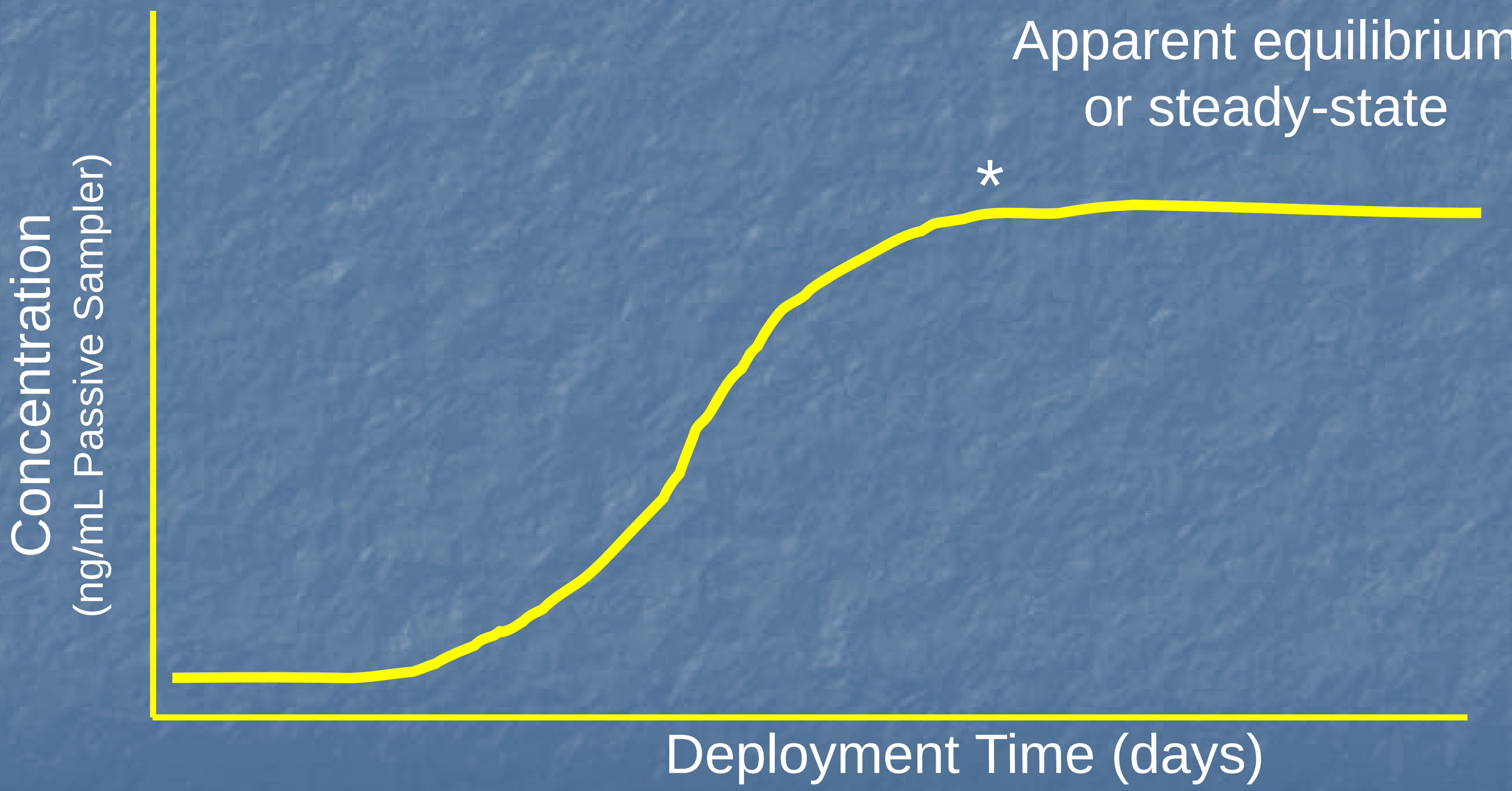
- Various plastics used as a surrogate for aquatic organisms.
- Rely on diffusion of chemicals from sediment to the sampler to reach equilibrium.
- Used to mimic benthic organism absorption of hydrophobic organic chemicals (e.g., PCBs).

Passive Sampler Theory



From: R. Burgess, USEPA

Passive Sampler Theory



From: R. Burgess, USEPA

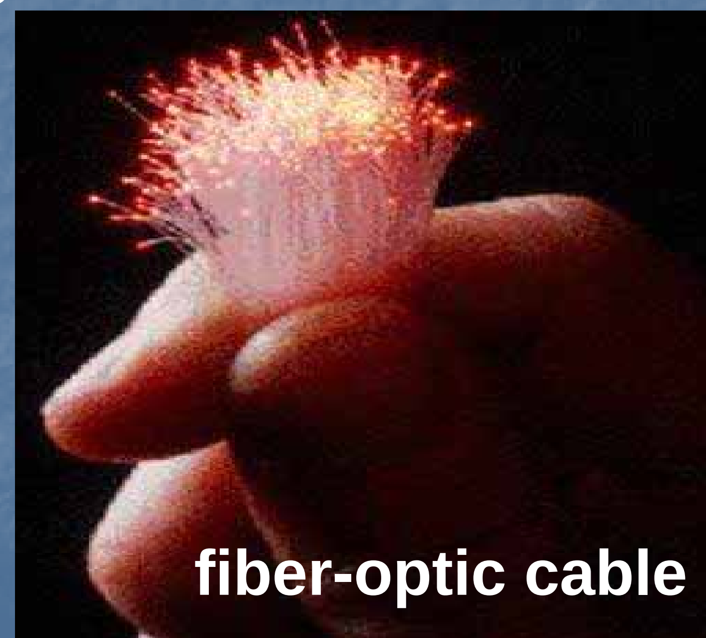
Types of Passive Samplers

0.25 m

2.5 cm

Polyethylene tubing
(70-95 um thick)

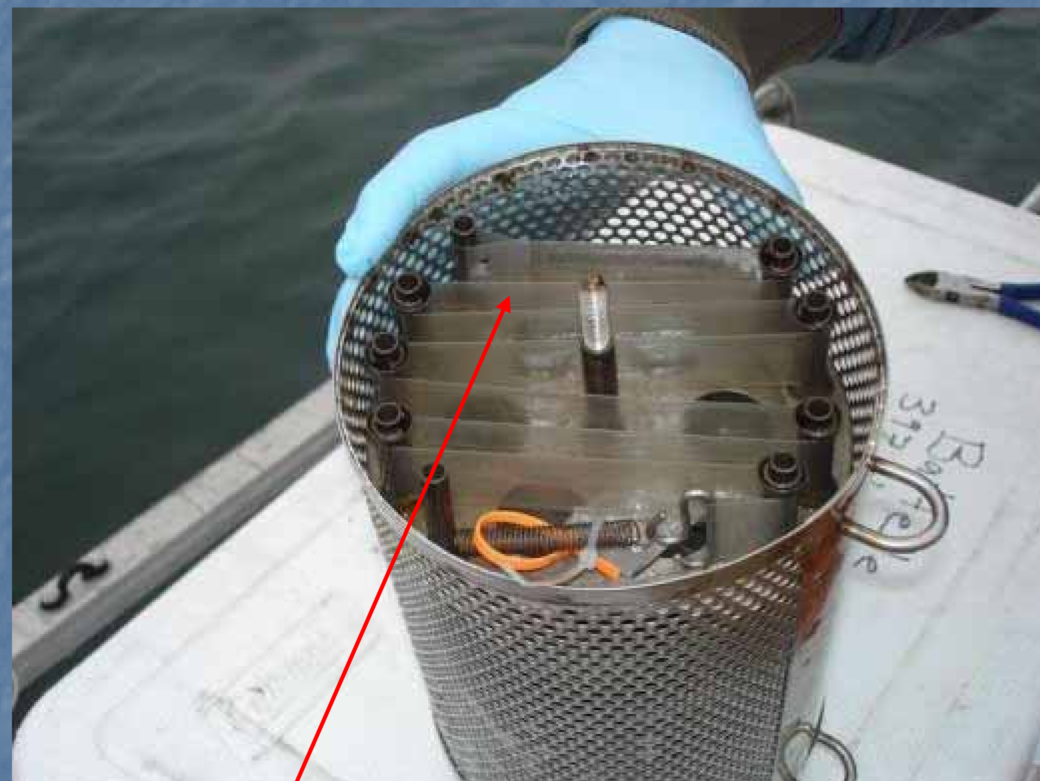
polyethylene
sheet



From: R. Burgess, USEPA

Passive Samplers

Poly Ethylene Device (PED)



Semi-Permeable Membrane Device (SPMD)

From: R. Burgess, USEPA

Issues using Passive Samplers

- Determining absorption-diffusion equilibrium is difficult
  - Determining when equilibrium occurs
  - Relating sampler accumulation to animal bioaccumulation

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