# Phase I Predictive Ecological Risk Assessment Guidance

## Overview with Mine Site Example

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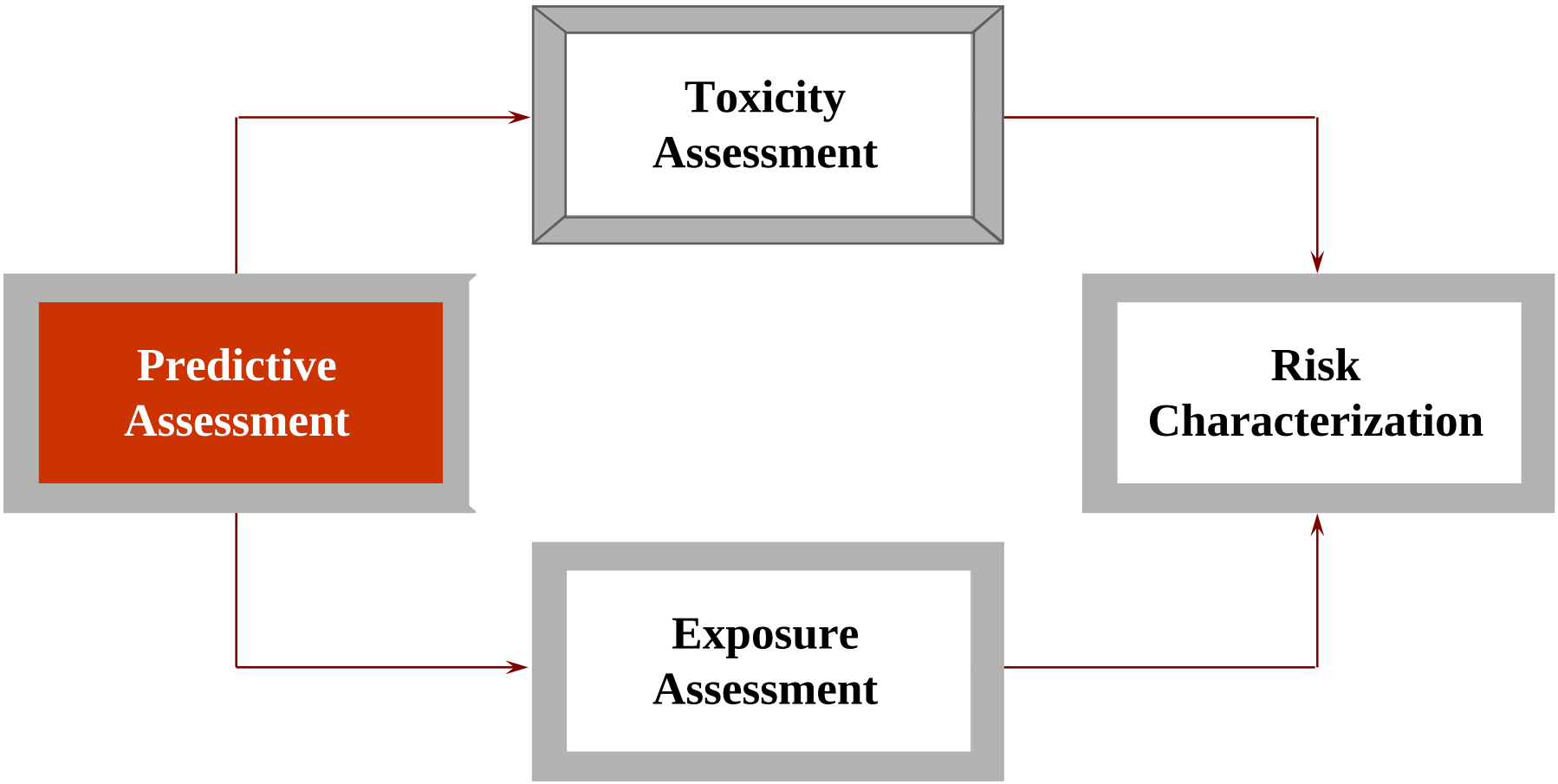
# Phase I Predictive Ecological Risk Assessment



# Phase I Predictive Ecological Risk Assessment Guidance

## Quantitative Assessment (with Toxicity Criteria)

**Steps**

1. Select representative species for assessment
2. Select assessment and measurement endpoints
3. Conduct exposure assessment (typically “modeled” with protective assumptions)
4. Select protective toxicity criteria
5. Risk characterization(generation of hazard quotients and indices with available toxicity criteria and exposure information).

# Step 1. Select Representative Species For Assessment

**It is not possible to assess all species occurring or expected to occupy the site: select "representative species" for each trophic level or feeding guild.**

# Selection Criteria for Representative Species

**Examples: see DTSC Guidance for full listing**

- Ecological Factors:  important prey species
- Toxicological Factors:  species similar to those used in standard laboratory bioassays
- Exposure Potential:  high site fidelity or likelihood of occurrence in specified habitat
- Societal Factors: representative of possible state or federally protected species occurring at the site

# Example Terrestrial Representative Species

# Representative Species (Terrestrial Mine Site)

| Guild | Species Selected | Attributes |
|---|---|---|
| 1º Producer | "Plant" | Base of the food chain |
| Detritivore | "Invertebrate" | Critical prey species, nutrient recycling |
| 1º Consumers | Ground Squirrel | Eats primarily plant material, high site fidelity, burrows |
| | White Crown Sparrow | Eats primarily plant material |

# Representative Species (Terrestrial Cont.)

| Guild | Species Selected | Attributes |
|---|---|---|
| 2º Consumer | Shrew | Eats invertebrates, high site fidelity, high exposure potential, burrows |
| | Robin | Eats invertebrates and some plant material, high exposure potential |
| 3º Consumers**<br><br>**Consider size of affected habitat | Coyote | Eats mostly small mammals, societal value, further assess food chain impacts |
| | Hawk | |

# Example Wetland Representative Species

# Representative Species (Wetland Mine Site)

| Guild | Species Selected | Attributes |
|---|---|---|
| 1º Producer | Algae<br><br>Macrophyte (rooted aquatic plant) | Base of the food chain |
| Detritivore/ 1º Consumer | Zooplankton (free floating invertebrates)<br><br>Benthic Invertebrates | Critical prey species, nutrient recycling |

# Representative Species (Wetland Cont.)

| Guild | Species Selected | Attributes |
|---|---|---|
| 1º & 2º Consumers | "Fish" | Eats invertebrates, important prey species, societal and recreational value |
| | Yellow-legged frog | Eats plant material and invertebrates, important prey species, high societal value (endangered species) |
| | Rail (marsh bird) | Eats benthic invertebrates, high site fidelity, high exposure potential |

# Representative Species (Wetland Cont.)

| Guild | Species Selected | Attributes |
|---|---|---|
| 3º Consumers**<br><br>**Consider size of affected habitat | River Otter | Eats fish and aquatic invertebrates, societal value, further assess food chain impacts |
| | Great Blue Heron | |

# Representative Species (Cont.)

**What about other common or expected terrestrial species, for example the soil/sediment microbial community (bacteria/fungi), amphibians (adult stages), or reptiles (snakes, lizards, turtles)?**

- Lack of toxicity information
- Assume protection of other species assessed in the risk assessment is protective of these species or communities.

**Describe in the Uncertainty Assessment.**

# Step 2. Select Assessment and Measurement Endpoints

- Focuses the risk assessment
  - What are we trying to protect?

# Select Assessment and Measurement Endpoints

**Assessment Endpoints**

- Attribute(s) considered to be critical to the function of the biological community or population - may assign "level of protection"
- Focus of the risk assessment.

**Measurement Endpoints**

- Measurable change that is used to evaluate effects of chemical(s) on selected assessment endpoints.

# Assessment and Measurement Endpoints: Mine Site Example (Terrestrial Habitat Examples, Not Inclusive)

| Assessment Endpoints | Representative Species | Example Measurement Endpoints |
|---|---|---|
| **Protect and maintain a health plant community** | "Plant" | ◆**Soil Toxicity Values (mg/kg)**<br>◆**Soil Porewater Tox. Values (µg/L)**<br>◆**Plant Distribution/Abundance Surveys. Compare to reference site.**<br>◆**Plant Tissue Concentrations**<br>◆**Soil Toxicity Tests** |
| **Protect and maintain a healthy soil invertebrate community**<br><br>**Provide prey for upper trophic level species** | "Invertebrate" | ◆**Soil Toxicity Values (mg/kg)****<br>◆**Soil Toxicity Tests**<br><br>****Low effects level** |
| **Protect _____ populations: survival and reproductive success.** | **Ground Squirrel**<br>**Shrew**<br>**Robin**<br>**White-Crowned Sparrow** | ◆**Toxicity reference values or Doses (mg/kg day$^{-1}$)**<br>**NOAELs** |

# Representative Species/Assessment Endpoints Selection

**Completed.**

- **Next Step: Exposure Assessment**

# Step 3. Exposure Assessment

**Key Concepts:**

- **Exposure Point Concentration (EPC)**
- **Wildlife Exposure Factors**
- **Tissue Concentrations and Food Chain Modeling****
  - Important concepts:
    - Bioconcentration
    - Bioaccumulation
    - Biomagnification
- **Bioavailability**

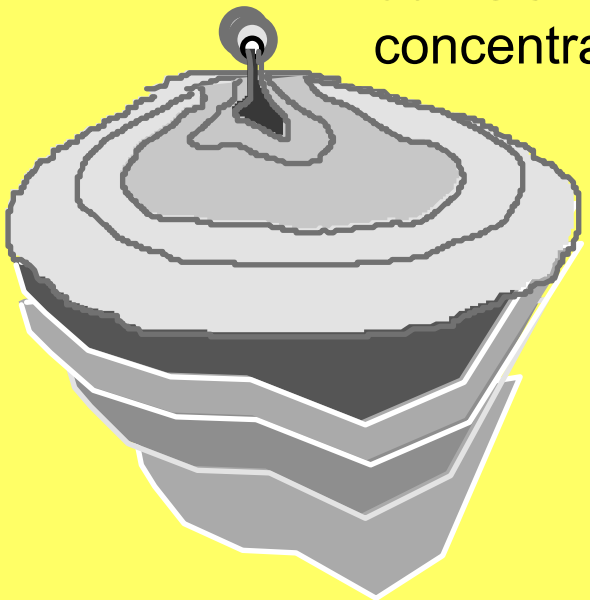
****Important Consideration: Chemical and physical properties assessment of each COPEC**

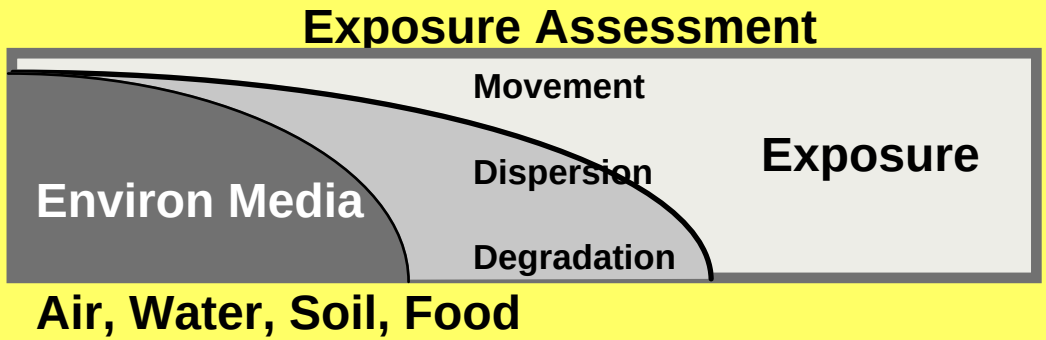
# Exposure Assessment

## Key Concept

### Exposure Point Concentration (EPC)

95th UCL on the arthmetic mean and/or Maximum concentration (e.g., soil, water, tissue)





# Exposure Assessment

## Key Concept (EPCs Cont.)

| Representative Species | Potentially Site Relevant Media of Concern | Exposure Point Concentration |
|---|---|---|
| **Plants** | •Soil | $EPC_{soil}$ |
| | •Sediment | $EPC_{sediment}$ |
| | •Groundwater | $EPC_{groundwater}$ |
| | •Surface water | $EPC_{surface\ water}$ |
| **Invertebrates** | •Soil | $EPC_{soil}$ |
| | •Sediment | $EPC_{sediment}$ |
| | •Surface water | $EPC_{surface\ water}$ |

# Exposure Assessment

## Key Concept (EPCs Cont.)

| Representative Species | Potentially Site Relevant Media of Concern | Exposure Point Concentration (EPC) |
|---|---|---|
| **Wildlife** | •Soil<br>•Sediment<br>•Surface water (including groundwater seeps) | $EPC_{soil}$<br>$EPC_{sediment}$<br>$EPC_{surface\ water}$ |
| | •Tissue conc. or body burden of prey species (modeled or directly measured) | $EPC_{plant}$<br>$EPC_{invertebrate}$<br>$EPC_{small\ mammal}$ |

# Exposure Assessment

## Key Concept - Wildlife Exposure Factors

| Parameter | Some Information Sources |
|---|---|
| **Dietary Preferences** | ◆USEPA Wildlife Exposure Factors Handbook (1993)<br>◆DFG California Species Database<br>◆OEHHA Cal/Ecotox Database |
| **Feeding Rates** | ◆Nagy (2001)<br>◆OEHHA Cal/Ecotox Database |
| **Soil/Sediment Ingestion Rates** | ◆Beyer et al. (1994)<br>◆OEHHA Cal/Ecotox Database<br>◆Hui and Beyer (1998) |
| **Home or Foraging Range** | ◆USEPA Wildlife Exposure Factors Handbook (1993)<br>◆DFG California Species Database |
| **Body Weights** | ◆USEPA Wildlife Exposure Factors Handbook (1993)<br>◆CRC Handbook (1995)<br>◆OEHHA Cal/Ecotox Database<br>◆Nagy (2001) |

# Exposure Assessment

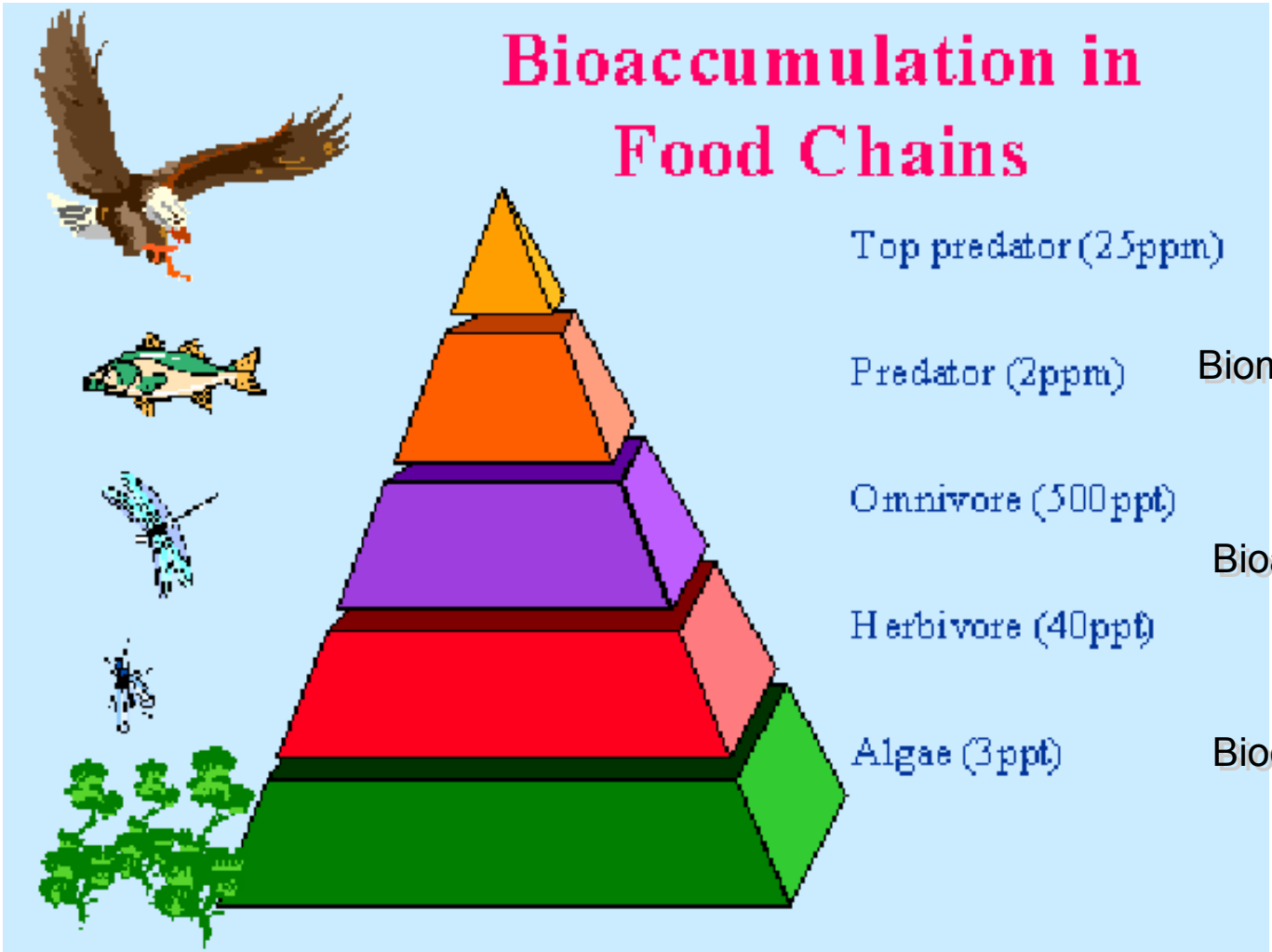
**Key Concept: Tissue Concentrations and Food Chain Modeling**

Definitions:

- Bioconcentration
- Bioaccumulation
- Biomagnification

****Important consideration: assess chemical and physical properties of each COPEC

# Exposure Assessment



# Exposure Assessment: Terrestrial Mine Site Example (Main COPEC Arsenic)

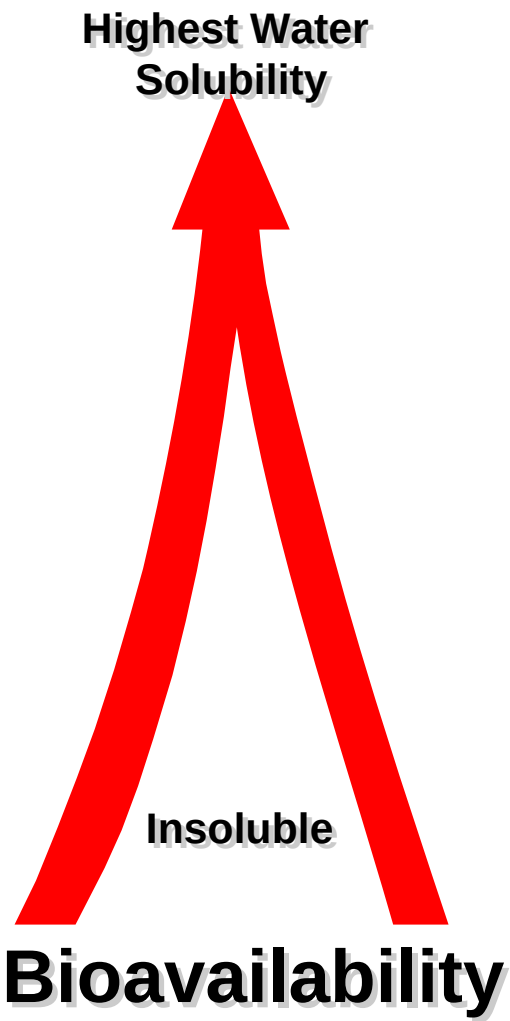
## Key Concept: Chemical-Physical Properties Assessment

- Arsenic (C.A.S. 7440-38-2) naturally occurring element in the earth's crust.
- Inorganic arsenic usually found combined with one or more other elements such as oxygen, chlorine, and sulfur.
- Arsenic combined with carbon and hydrogen is referred to as organic arsenic. The organic forms are usually less toxic than the inorganic forms.
- Inorganic arsenic compounds are solids at normal temperatures and are not likely to volatilize.
- Due to human activities, such as mining or smelting, naturally immobile arsenics can be mobilized and be found in higher concentrations than where they existed naturally.

# Key Concept: Bioavailability

**Potential Forms of Arsenic in the Environment**

- **Sodium arsenite**
- **Arsenic acids**
- **Manganese or iron arsenic complexes**
- **Arsenic trisulfide**



# Exposure Assessment: Terrestrial Mine Site Example

## Hypothetical Exposure Data

## Soil/Tailings Site $EPC_{soil}$ (0 to 6 ft below surface):

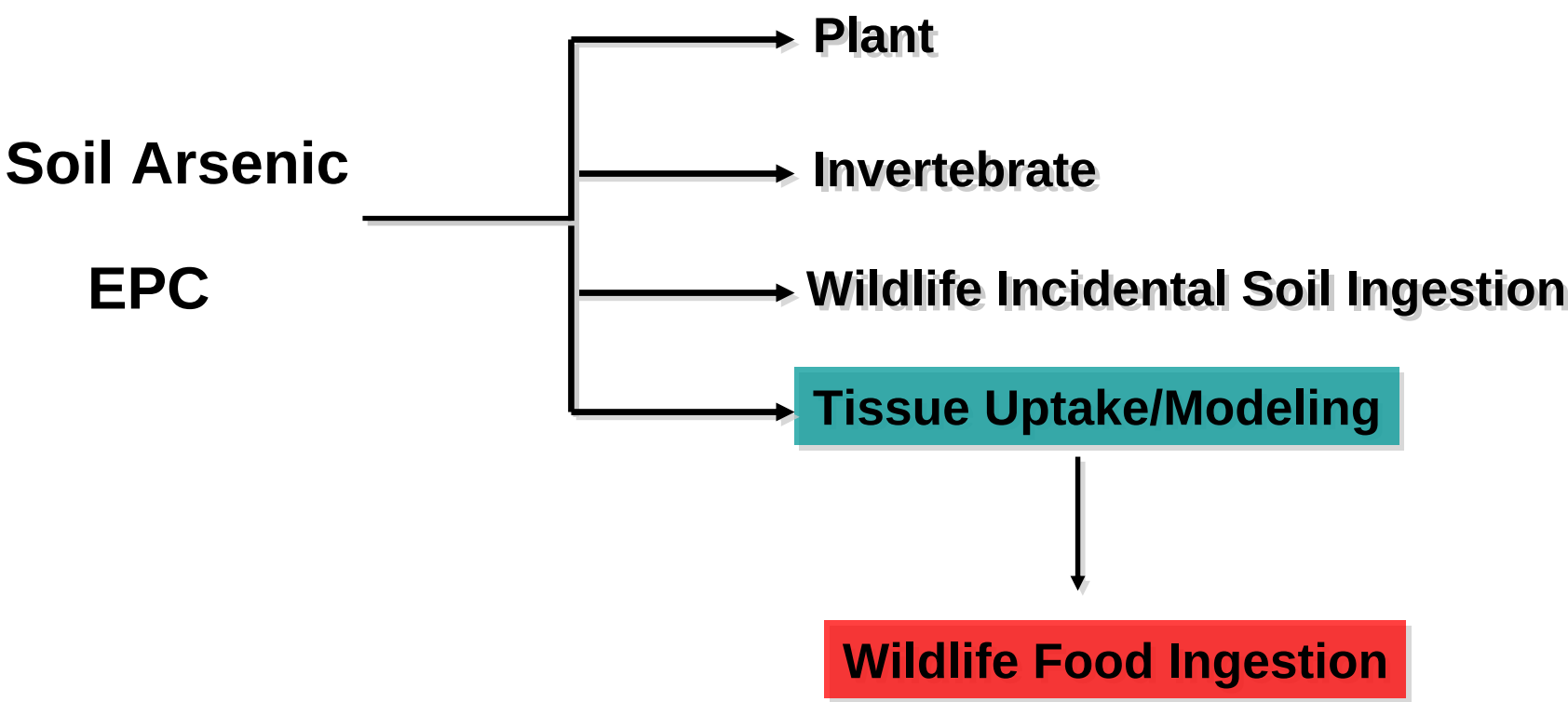
**2.5 Acre Site**

**$Arsenic_{[Max]}$ = 119 mg/kg**

**$Arsenic_{[95th\ UCL]}$ = 81 mg/kg**

**$Arsenic_{[Background]}$ = 15 mg/kg**

# Exposure Assessment: Terrestrial Mine Site Example



# Exposure Assessment: Terrestrial Mine Site Example

## Tissue Uptake/Modeling

**Estimate Prey Tissue Concentrations Using Literature-Derived Bioaccumulation Factors (BAFs)**

**Herbivore (plant eating)**

$$EPC_{soil} * BAF_{plants} = EPC_{plants}$$ (Plant Tissue Conc.)

**Invertivore (invertebrate eating)**

$$EPC_{soil} * BAF_{invert} = EPC_{invert}$$ (Invert. Tissue Conc.)

**Carnivore (flesh eating)**

$$EPC_{soil} * BAF_{prey} = EPC_{prey}$$ (Small Mammal Tissue Conc.)

# Exposure Assessment: Terrestrial Mine Site Example

## Tissue Uptake/Modeling

**Estimate Prey Tissue Concentrations of Arsenic Using Literature-Derived Bioaccumulation Factors (BAFs)**

| Feeding Guild | $EPC_{Soil}$ (mg/kg) | Arsenic BAF** (point estimate or regression) | Arsenic $EPC_{Tissue}$ (mg/kg) |
|---|---|---|---|
| HERBIVORE | 119 | $BAF_p = 0.03752 * EPC\ soil$ where p = plants | 4.46 |
| INVERTIVORE | 119 | $Ln(BAF_i) = 0.0706 * ln(EPC\ soil) - 1.421$ where i =earthworm | 0.34 |
| CARNIVORE | 119 | $Ln(BAF_m) = 0.8188 * ln(EPC\ soil) - 4.8471$ where m = small mammal prey | 0.39 |

**BAF Source: USEPA EcoSSL Guidance

# Exposure Assessment: Terrestrial Mine Site Example

## Wildlife Food Ingestion

**Parameters Used to Estimate Food Ingestion in Wildlife: Example 1**

**Literature-Derived Parameters to estimate Ornate Shrew Food and Soil Ingestion Rates**

- Average ornate shrew body weight (BW) = 0.0055 kg[1]
- Adult ornate shrew consumes 0.0011 kg invertebrates/day[2]
- Adult ornate shrew incidentally ingests 4% of its total food intake as soil[3]
- Adult ornate shrew forages over 0.2 acre max. (assume contaminated area encompasses shrew's foraging range)[4]

**Sources:** 1. CRC Handbook of Mammalian Body Masses (1995); 2. Nagy (2001) insectivorous mammal dry matter intake; 3. Beyer et al. (1994) average estimate for voles/mice; 4. Foraging range of the vagrant shrew (surrogate) US Forest Service **(2007).**

# Exposure Assessment: Terrestrial Mine Site Example

## Wildlife Food Ingestion

**Parameters Used to Estimate Food Ingestion in Wildlife: Example 2**

**Literature-Derived Parameters to estimate Ground Squirrel Food and Soil Ingestion Rates**

- Average ground squirrel body weight (BW) = 0.584 kg[1]
- Adult ground squirrel consumes 0.047 kg plant material/day[2]
- Adult ground squirrel incidentally ingests 5.0 % of its total food intake as soil[3]
- Adult ground squirrel forages over 0.5 acre max. (assume contaminated area encompasses squirrels foraging range)[4]

**Sources:** 1. CRC Handbook of Mammalian Body Masses (1995); 2. Nagy (2001) herbivorous mammal, dry matter intake; 3. Beyer et al. (1994) estimate; 4. California's Wildlife (DFG website): average home/foraging range estimate.

# Exposure Assessment: Terrestrial Mine Site Example

- For purposes of this site scenario, we will assume that wildlife receive their primary exposure (dose) via ingestion of food ($EPC_{tissue}$) and ingestion of soil ($EPC_{soil}$).

- Other exposure routes, including dermal adsorption and inhalation (i.e., dusts), are considered minor relative to the other exposure routes above, and are not directly quantified.

- Surface water ingestion from a nearby wetland may be a relevant exposure pathway, however, for purposes of time, these calculations are not evaluated in this example.

# Exposure Assessment: Terrestrial Mine Site Example

Example Wildlife Dose Calculation (mg/kg BW $Day^{-1}$):

**Daily intake by mammal = CM * CR * FI * AF * $BW^{-1}$**

CM = concentration in media of concern ($EPC_{soil}$ and $EPC_{tissue}$)

CR = contact rate (e.g., amount ingested)

FI = fraction of time spent on site

AF = adsorption factor (e.g., fraction absorbed by the gut)

BW = body weight of species

# Exposure Assessment: Terrestrial Mine Site Example

**Shrew-Specific Intake Algorithm:**

Daily intake = {(Invertebrate [As] mg/kg * Shrew Ingestion Rate) + (Soil [As] * 0.04 * Shrew Ingestion Rate)} * FI * AF * $BW^{-1}$

$$= \frac{\{(0.34_{\text{ mg/kg}} * 0.0011_{\text{ kg food/day}}) + (119_{\text{ mg/kg}} * 0.04 * 0.0011_{\text{kg food/day}})\} * 1 * 1}{0.0055 \text{ kg BW}}$$

Maximum Daily Shrew Intake = **1 mg/kg BW $Day^{-1}$**

# Exposure Assessment: Terrestrial Mine Site Example

## Squirrel-Specific Intake Algorithm:

Daily intake = {(plant [As] mg/kg * Squirrel Ingestion Rate) + (Soil [As] * 0.04 * Shrew Ingestion Rate)} * FI * AF * $BW^{-1}$

$$= \frac{\{(4.46\ _{mg/kg} * 0.047_{kg\ food/day}) + (119\ _{mg/kg} * 0.05\ * 0.0024\ _{kg\ food/day})\} * 1 * 1}{0.584\ \text{kg BW}}$$

Maximum Daily Squirrel Intake = **0.38 mg/kg BW $Day^{-1}$**

# Exposure Assessment: Terrestrial Mine Site Example

**Completed.**

- **Next Step: Toxicity Assessment**

# Step 4. Toxicity Assessment

- **Toxicity Criteria used in the Phase I Risk Assessment**
  - Usually not site-specific
  - Based primarily on laboratory testing results from the scientific literature**

    ****Caveat: bioavailability of chemical in the field may not equal bioavailability of chemical tested in the laboratory**

  - No observable adverse effect level (NOAEL)
  - Lowest observable adverse effect level (LOAEL).

# Toxicity Assessment

## Some Sources for Wildlife TRVs

| Representative Species | Source | Web Link |
|---|---|---|
| Birds & Mammals | USEPA Region 9 Biological Technical Assistance Group (BTAG) | http://www.dtsc.ca.gov/AssessingRisk/eco.cfm |
| Plants<br>Invertebrates<br>Birds<br>Mammals | USEPA Ecological Soil Screening Levels Guidance (EcoSSLs) | http://www.epa.gov/ecotox/ecossl/SOPs.htm |
| | Oakridge National Laboratory (ORNL) | http://www.esd.ornl.gov/programs/ecorisk/ecorisk.html |
| Amphibians | Environment Canada | http://www.cws-scf.ec.gc.ca/publications/AbstractTemplate.cfm?lang=e&id=321 |
| | USEPA | http://www.epa.gov/waterscience/criteria/aqlife.html |
| Algae, Invertebrates (freshwater & marine), Fish | USEPA Ambient Water Quality Criteria | http://www.epa.gov/waterscience/criteria/aqlife.html |
| Benthic Invertebrates (freshwater & marine sediment) | National Oceanic and Atmospheric Administration (NOAA) | http://response.restoration.noaa.gov/book_shelf/122_squirt_cards.pdf |
| Fish (sediment) | NOAA | http://www.nwfsc.noaa.gov/publications/displayallinfo.cfm?docmetadataid=3323<br>http://www.nwfsc.noaa.gov/publications/displayallinfo.cfm?docmetadataid=3906<br>http://www.nwfsc.noaa.gov/publications/displayallinfo.cfm?docmetadataid=3999 |

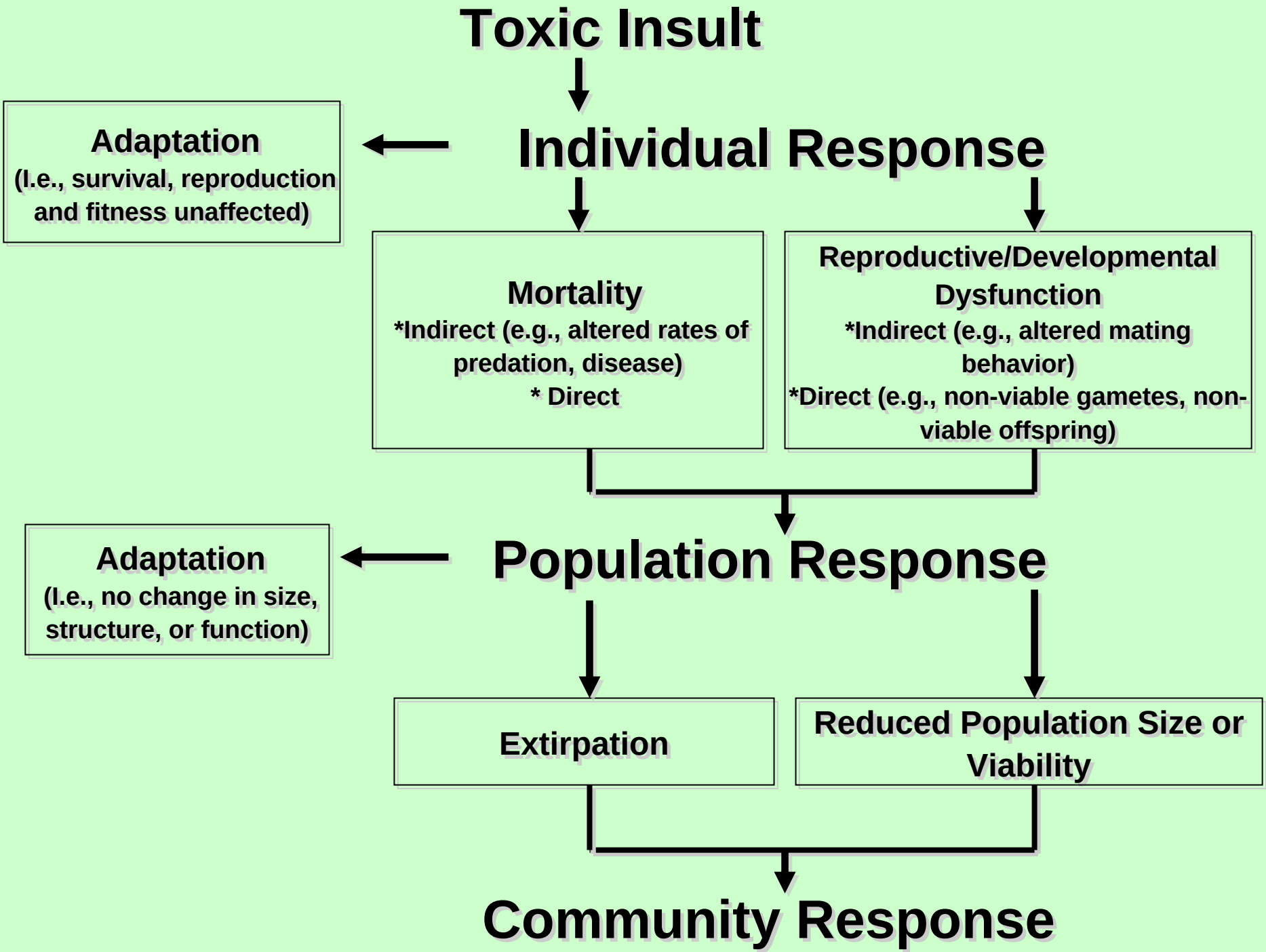
# Toxicity Assessment

- **Toxicity Criteria used in the Risk Assessment (Cont.)**
  - Chronic no observable adverse effect level (NOAEL). Represents a “safe” dose (i.e., without adverse effect)
  - Chronic lowest observable adverse effect level (LOAEL) or lowest adverse effect concentration (LOAEC). Represents dose or media concentration that potentially causes an adverse effect
  - Relate to assessment and measurement endpoints
  - Assign level of protection required by risk assessment.

# Toxicity Assessment

- **Toxicity Criteria used in the Phase I Risk Assessment (Cont.)**
  - Toxicity Reference Values (TRVs)
    - Plants and Invertebrates: LOAEC-based (toxicity and ecological literature supports even with some loss of individuals, population/community survives)
    - Wildlife (mammals & birds): NOAEL-based** (lack of literature/precedent: unknown how loss of individuals may affect population, therefore use most protective toxicity criteria)

**assume NOAEL also protective of endangered species


Toxic Insult
Individual Response
Adaptation
(I.e., survival, reproduction and fitness unaffected)
Mortality
*Indirect (e.g., altered rates of predation, disease)
* Direct
Reproductive/Developmental Dysfunction
*Indirect (e.g., altered mating behavior)
*Direct (e.g., non-viable gametes, non-viable offspring)
Population Response
Adaptation
(I.e., no change in size, structure, or function)
Extirpation
Reduced Population Size or Viability
Community Response

# Toxicity Assessment: Terrestrial Mine Site Example

**What is the "population" we are trying to protect? (refer back to the assessment endpoints)**

- **Population of plants and animals inhabiting the 2.5 acre site?**
- **Population of plants and animals in Placer County?**
- **Population of plants and animals in Sierra Foothills habitats?**
- **Population of plants and animals in California?**

# Toxicity Assessment: Terrestrial Mine Site Example

Selected Toxicity Reference Values
(Arsenic Example)

| Representative Species | Value | Source Test Chemical |
|---|---|---|
| Plant | 18 mg/kg soil<br>Geometric mean of NOAEC & LOAEC | USEPA EcoSSLs<br>Arsenates and Arsenites |
| Invertebrate | 60 mg/kg soil<br>LOAEC | ORNL<br>Potassium arsenate |
| Bird | 5.5 mg/kg BW $day^{-1}$<br>NOAEL | BTAG<br>Sodium arsenate |
| Mammal | 0.32 mg/kg BW $day^{-1}$<br>NOAEL | BTAG<br>Sodium arsenite |

# Toxicity Assessment

**Completed.**

- **Next Step: Risk Characterization**

# Step 5. Risk Characterization

- **Quantify Potential Ecological Hazards**

**Hazard Quotient or Index (HQ or HI) =**

$$\frac{\text{EPC}}{\text{Toxicity Reference Value (NOAEL/LOAEL/LOAEC)}}$$

**If HQ or HI > 1** → **unacceptable risk? confirm via Phase II**

# Risk Characterization: Terrestrial Mine Site Example

| Representative Species | Exposure Values | Toxicity Value | Hazard Quotient (HQ) | Confidence in the HQ | |
|---|---|---|---|---|---|
| | | | | Exposure Potential | Toxicity Value |
| Plant | 119 mg/kg (Max)<br>81 mg/kg (95$^{th}$ UCL) | 18 mg/kg soil | 7<br>5 | Low** | High |
| Invertebrate | 119 mg/kg (max)<br>81 mg/kg (95$^{th}$ UCL) | 60 mg/kg soil | 2<br>1.3 | Low | Low |
| Bird (White-Crowned Sparrow) | 1.4 mg/kg BW day$^{-1}$ (MAX) | 5.5 mg/kg BW day$^{-1}$ | 0.3 | Low | Moderate |

**Low confidence in exposure assumptions; however, we assume a protective "worst case" or highly bioavailable exposure scenario.

# Risk Characterization: Terrestrial Mine Site Example

| Representative Species | Exposure Values | Toxicity Value | Hazard Quotient (HQ) | Confidence in the HQ | |
|---|---|---|---|---|---|
| | | | | Exposure Potential | Toxicity Value |
| Mammal (Ground Squirrel) | 0.38 mg/kg BW day$^{-1}$ (MAX) | 0.32 mg/kg BW day$^{-1}$ | 1.2 | Low | High |
| | 0.37 mg/kg BW day$^{-1}$ (95$^{th}$ UCL) | | 1.2 | | |
| Mammal (Ornate Shrew) | 1.0 mg/kg BW day$^{-1}$ (MAX) | | 3.2 | Low | High |
| | 0.71 mg/kg BW day$^{-1}$ (95$^{th}$ UCL) | | 2.2 | | |
| **Low confidence in exposure assumptions; however, we assume a protective "worst case" or highly bioavailable exposure scenario. | | | | | |

# Risk Characterization

**Report**

- Representative species
- Assessment/measurement endpoints
- HQs and HIs (and all supporting data to reproduce calculations)
- Draw together various lines-of-evidence
- Uncertainty Assessment
  - Exposure assumptions
  - Toxicity assumptions

**If Required: Establish Soil-Based Ecological Preliminary Remediation Goals (Consider arsenic and other chemicals)**

# Risk Management Decision-Making and Ecological Risk

- **Lines-of-Evidence Needed for Risk-Management Decision Making:**
  - Identified chemicals of concern and potential exposure pathways
  - Range of representative species evaluated (i.e., including special status species)
  - Persistence and bioaccumulation potential of chemical(s) of concern
  - Bioavailability

# Risk Management Decision-Making and Ecological Risk

- **Lines-of-Evidence Needed for Risk-Management Decision Making (Cont.)**
  - Uncertainty contained in exposure models (e.g., estimated intake levels and site use factors)

# Risk Management Decision-Making and Ecological Risk

- **Lines-of-Evidence Needed for Risk-Management Decision Making (Cont.)**

  - Magnitude of the hazard quotients or hazard indices generated from the NOAEL or LOAEL toxicity values

# Risk Management Decision-Making and Ecological Risk

- **Lines-of-Evidence Needed for Risk-Management Decision Making (Cont.)**
  - Toxicological endpoint of the toxicity value used to calculate the hazard quotients or indices (i.e., NOAEL, LOAEL)
  - Cumulative risk (i.e., risks derived from more than one chemical exposure, risks evaluated site-wide)
  - Toxicological endpoint, laboratory species tested, and magnitude of any uncertainty factors used to develop the final toxicity value (i.e., that value proposed to calculate a target cleanup level)
  - Estimated and potentially field-verified toxicity evaluations

# Risk Management Decision-Making and Ecological Risk

- **Lines-of-Evidence Needed for Risk-Management Decision Making (Cont.)**
  - Any potential adverse effects of remediation on sensitive ecological habitats.
  - Current and future land use

# Risk Characterization: Terrestrial Mine Site Example

**Risk Management Decision Point**

**Looks like there could be a problem for plants and small mammals. Options:**

- Remediate
  - Demonstrate protection of human health is protective of ecological receptors (including wetland species, if present)
  - Bioavailability assessment or cleanup to background levels

– OR –

- Further Study (Phase II Validation Study)
  - **Bioavailability assessment**
  - Exposure reassessment (collect site plant/invert. tissues)
  - Toxicity bioassays
  - Prepare refined soil cleanup levels

# REFERENCES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