Learning about risk assessment with emphasis on metals

Charlie Menzie
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camenzie@exponent.com

What we will cover

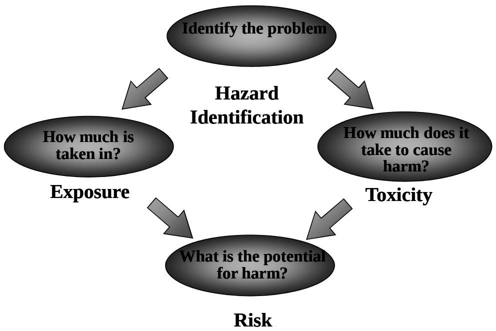
- Definitions
- Getting started
- Exposure assessment
- Effects assessment
- Risk characterization

What is Risk Assessment?

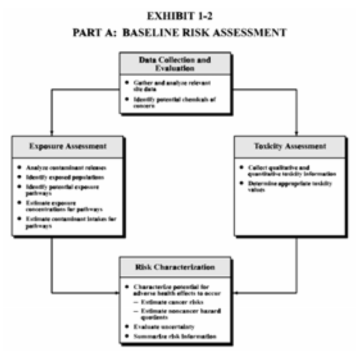
Risk assessment is defined as a process that evaluates the likelihood that adverse effects may occur or are occurring as a result of exposure to one or more stressors

EPA Risk Assessment Forum
1992

How Does Risk Assessment Work?

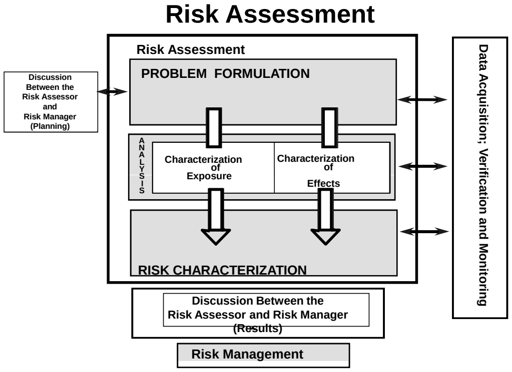


Superfund human health baseline risk assessment



http://www.epa.gov/oswer/riskassessment/ragsa/index.htm

Framework for Risk Assessment

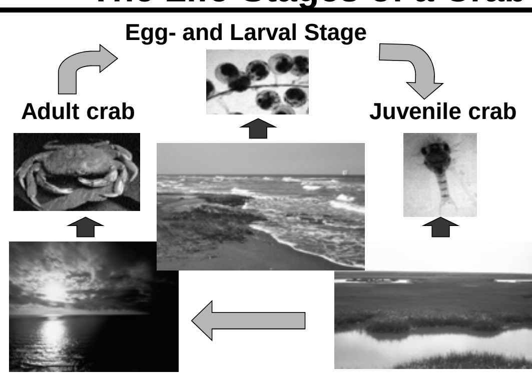


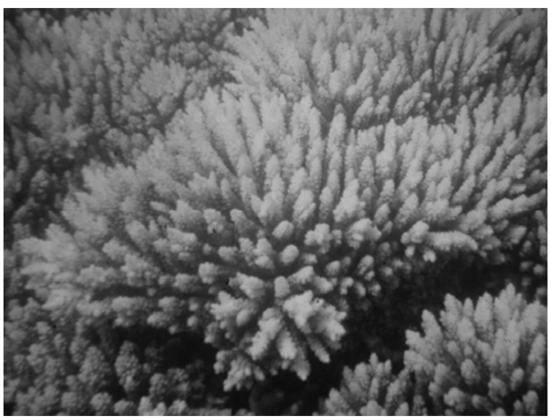
Some Challenges and a Bit of Philosophy

Comparison of Receptor Organizational Levels and Categories

	Ecological Receptors	Human Receptors
Organizational Level	Ecosystem Community Population Individual *Sensitive Lifestages*	Individual *Sensitive Humans*
Examples of Individual Level Classification	a) By Species b) By Group of Similar Species c) By Indicator Species	a) By Nature and Function of Visit (e.g. trespasser, worker, resident)

The Life-Stages of a Crab





A Brief Philosophical Observation

- All human lives (are supposed to be) valued equally
- Values of ecological receptors varies depending on points of view and ecological knowledge
  - ✓ small, hard to see animals not highly valued by average person (but may be very important)
  - ✓ furry, finned or feathered, upper trophic levels are highly valued
- Value also increases with increasing level of organization
  - ✓ well being of individual benthic worm versus benthic community

A very simple perspective on how we estimate risk?

- Exposure estimate < toxicity value = effects are unlikely
- Exposure estimate > toxicity value = potential for effects may exist

Risk assessment beginnings?

Is this a Risk Assessment?

The acute oral dose of cadmium estimated to kill 50% of exposed animals (LD50) is 890 mg/kg (in the mouse)

Is this an Risk Assessment?

Elevated levels of lead (>2,000 mg/kg) have been detected in sub-surface soils in a large tract of land in the mid-west.

Is this a Risk Assessment?

A study reveals that sediments contain elevated levels of methyl mercury, a bioaccumulative chemical. Birds that exhibit body burdens of methyl mercury above a certain level may fail to reproduce. A food chain model and sampling indicated that chemicals are being transported from the sediments to the birds. The analysis compares measured and estimated body burdens in the birds to the literature values for toxic effects.

Is This a Risk Assessment?

A power plant on a large river is predicted to draw in large numbers of fish larvae in its cooling water. Tests show that the survival of the larvae is low. An analysis is performed to determine if the mortality of larvae could affect the fish population.

Is This a Risk Assessment?

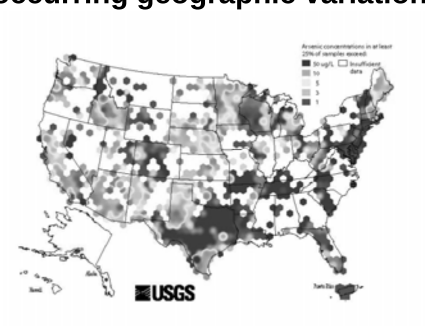
The water level of a low-lying area is predicted to rise by tens of feet. The animals in the area have limited swimming ability and could drown. A topographic survey indicates that high lands that could be used as refuge, are limited. A judgment is made that intervention is needed to preserve biodiversity.

The risk management decision

We will emphasize metals so let's start with the five principles of EPA's Metals Framework

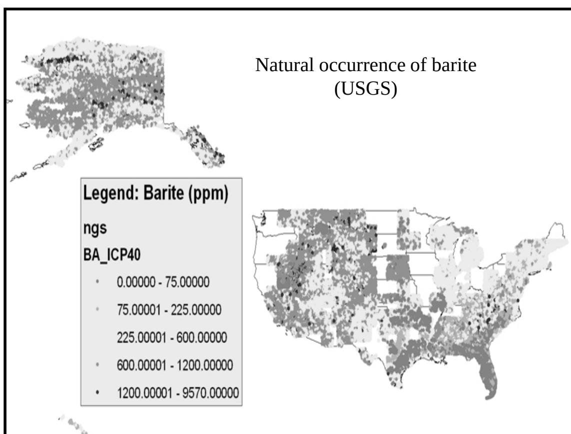
1. Metals are naturally occurring constituents in the environment and vary in concentrations across geographic regions.
2. Metals often exist in the environment as mixtures
3. Some metals are essential for maintaining proper health of organisms
4. Environmental chemistry strongly influences their fate and effects of metals
5. The toxicokinetics and toxicodynamics of metals depend on the metal, the form of the metal or metal compound, and the organism's ability to regulate and/ or store the metal.

Arsenic: an example of naturally occurring geographic variation



Ryker, S.J., Nov. 2001, Mapping arsenic in groundwater: Geotimes v.46 no.11, p.34-36.

Natural occurrence of barite (USGS)



Essentiality and Toxicity

Some metals are **essential for health**	Some metals may be **beneficial for health**	Other metals have no known **beneficial health effects**
Cobalt	Arsenic	Aluminum
Chromium III	Boron	Antimony
Copper	Nickel	Barium
Iron	Silicon	Beryllium
Manganese	Vanadium	Cadmium
Molybdenum		Chromium VI
Selenium		Lead
Zinc		Mercury
		Silver
		Strontium
		Thallium
		Tin

***All metals (and other compounds) are toxic at high enough doses.**

Absolute Bioavailability

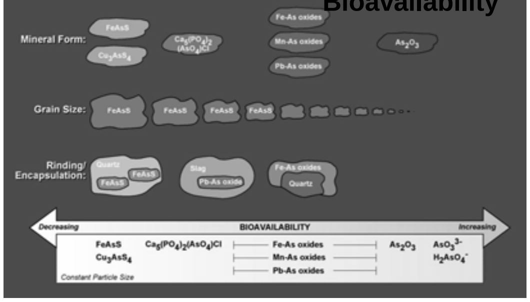
Fraction of intake reaching the central compartment; i.e., blood

Relative Bioavailability

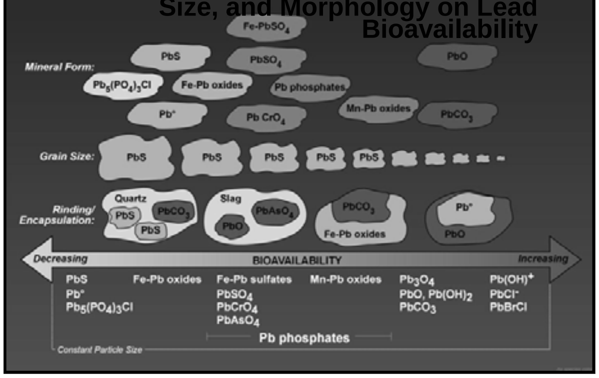
$$\text{RAF} = \frac{\text{Absorption for exposure medium of concern}}{\text{Absorption for medium used in toxicity study}}$$

RAF = Relative absorption factor

Influence of Arsenic Species, Particle Size, and Morphology on Arsenic Bioavailability



Influence of Lead Species, Particle Size, and Morphology on Lead Bioavailability



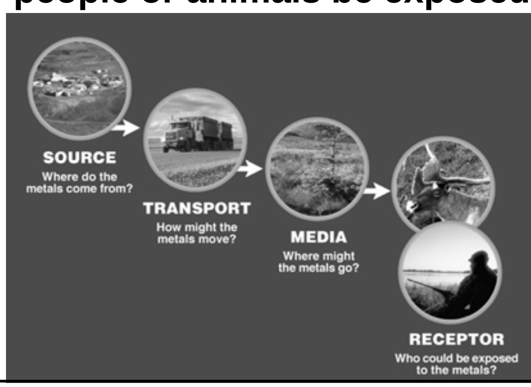
Other bioavailability Issues

- Bioavailability of metals varies widely
- Bioavailability should be explicitly considered in risk assessment
- Trophic transfer can be an important route of exposure for metals
- However, concentrations of inorganic forms of metals typically do not increase up the food chain, and often decrease

Example Assessment Questions for Metals

- BACKGROUND: How should background (natural and anthropogenic) levels for metals be characterized for the selected spatial scale of the assessment?
- MIXTURES: Are toxicological effects of metal mixtures being incorporated in the effects assessment?
- ESSENTIALITY: How will both toxicity and deficiencies of essential metals be characterized?
- METAL FORMS: Since environmental chemistry is a primary factor influencing metal speciation and subsequent transport, uptake, and toxicity, how will it be included in the risk assessment?

Getting started: How might people or animals be exposed?



Risk assessors refer to this most critical initial step as

- **Hazard identification**
- **Problem formulation**

Key first components include

- Identification of Chemicals of Potential Concern (COPCs)
  - ✓ Screening analyses for media
- A conceptual exposure model
  - ✓ Receptors
  - ✓ Pathways of exposure
- Assessment endpoints (ecological)
- Scoping for the assessment

What is a screening level?

- Definition: The concentration of a particular contaminant in a specific media that is considered to be protective of a wide range of receptors and habitats.
- Screening levels are NOT clean-up levels
- Regulatory acceptance and scientific basis for derivation and application of screening levels varies among media.

Examples of soil screening levels (USEPA, 2009)

Contaminant	Screening Levels	
	Residential Soil	Industrial Soil
Analyte	mg/kg	mg/kg
Antimony Pentoxide	3.9E+01	5.1E+02
Arsenic, Inorganic	3.9E-01	1.6E+00
Cadmium (Diet)	7.0E+01	8.0E+02
Cadmium (Water)		
Copper	3.1E+03	4.1E+04
Chromium III	1.2E+5	1.5E+6
Chromium VI	2.9E-1	5.6E+00
Lead Compounds		
~Lead and Compounds	4.0E+02	8.0E+02
~Tetraethyl Lead	6.1E-03	6.2E-02
Lead acetate	2.3E+00	1.0E+01
Lead subacetate	1.7E+01	7.5E+01
Mercury Compounds		
~Mercuric Chloride	2.3E+01	3.1E+02
~Mercuric Sulfide	2.3E+01	3.1E+02
~Mercury (elemental)	5.6E+00	3.4E+01
~Mercury, Inorganic Salts	2.3E+01	3.1E+02
~Methyl Mercury	7.8E+00	1.0E+02
~Phenylmercuric Acetate	4.9E+00	4.9E+01
Nickel Carbonyl	3.7E+03	4.4E+04
Nickel Oxide	3.8E+03	4.7E+04
Nickel Refinery Dust	3.7E+03	4.4E+04
Nickel Soluble Salts	1.5E+03	2.0E+04
Nickel Subsulfide	3.8E-01	1.7E+00
Silver	3.9E+02	5.1E+03

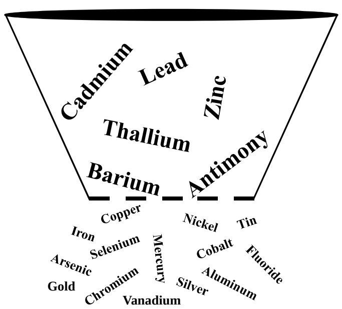
Source http://earth1.epa.gov/region09/superfund/prg/

Examples of sediment screening levels (USEPA)

Analyte	FW Sed (mg/kg)
Antimony	2
Arsenic	9.8
Cadmium	0.99
Chromium	43.4
Copper	31.6
Lead	35.8
Mercury	0.18
Methylmercury	
Nickel	22.7
Silver	1.0
Zinc	121

http://www.epa.gov/reg3hwmd/risk/eco/btag/sbv/fwsed/screenbench.htm#download

Screening helps delineate COPCs from the rest.



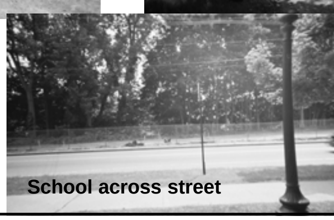
Developing a Site Conceptual Model

- **Typically: visual depictions of the relationships among sources, receptors, and exposure pathways (including media of concern)**
- **They may vary due to regional variability**
- **They are useful to**
  - ✓ **check for the presence of completed pathways**
  - ✓ **communicate to others what is known and not known about a site**

The Basic Idea of Conceptual Models

SOURCES	PATHWAYS	RECEPTORS
Metals and PAHs in park soil Arsenic levels exceed IH trigger	Surface Soil Fugitive Dust	Child (1-6 yrs.) playing in park 5 year exposure period Ingestion of soil Dermal contact with soil Inhalation of dust

We Think in terms of locations ….



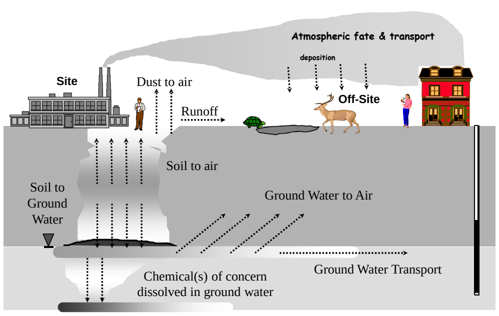
And in Terms of Receptors and Pathways

- **Residents drinking contaminated water**
- **Children playing in contaminated surficial soil**
- **People breathing contaminated indoor air**

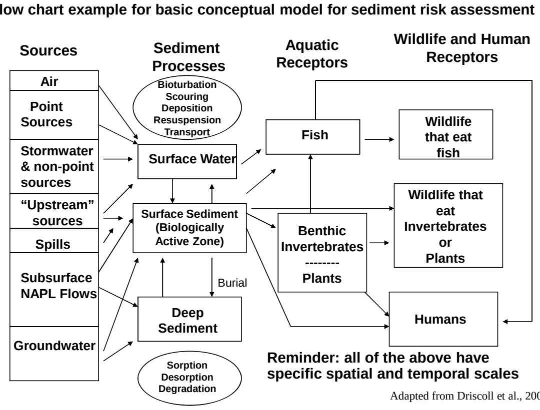
Conceptual models may include

- Pictorial representations
- Flow charts
- Narratives

Pictorial example: pathways and receptors



Flow chart example for basic conceptual model for sediment risk assessment



Reminder: all of the above have specific spatial and temporal scales

Adapted from Driscoll et al., 2001

What Are Assessment Endpoints?

Explicit expressions of the actual environmental value that is to be protected, operationally defined by an ecological entity and its attributes

Selection of Assessment Endpoints

- Ecological relevance
- Susceptibility to known or potential stressors
- relevance to management goals
  - ✓ social relevance
  - ✓ measurable or predictable
  - ✓ unambiguous operational definition
  - ✓ logically related to the decision

Source: EPA (1998)

Assessment Endpoints

- Population
  - ✓ Survival
  - ✓ Normal growth / development
  - ✓ Successful reproduction / recruitment
  - ✓ Yield / production
- Community
  - ✓ Species composition / diversity / abundance
  - ✓ Structure
- Ecosystem
  - ✓ habitat value to wildlife species
  - ✓ habitat abundance and distribution

Source: EPA (1998)

Case Study

I. THE SITE

A popular park area in a New England town has been found to be contaminated with lead chromate and other metals. The soils exhibit many colors and this has often attracted the attention of children. There is a school next to the park and the students often use the park for recreation. The metals on the uplands have migrated into wetland systems and also have entered a nearby pond and lake. The lake drains to a brook and the wetlands of this brook also have elevated levels of lead. There are residences along the brook.

In groundwater is contaminated with chromium and efforts have been made to delineate a plume.

Investigations have also shown that lead and other metals are present in sediments in shallow waters.

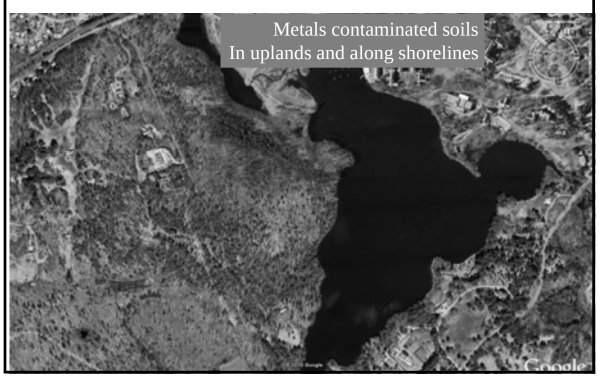
II. OTHER INFO

The soils at the site are sandy silts with an organic carbon content of 8 to 12 percent. The sediments in the wetland and lake river are silty sands with an organic carbon content of 2%. Flow ranges from 40 cfs (summer) to 820 cfs (spring runoff). Groundwater discharge from the site to the lake is approximately 10 cfs (summer).

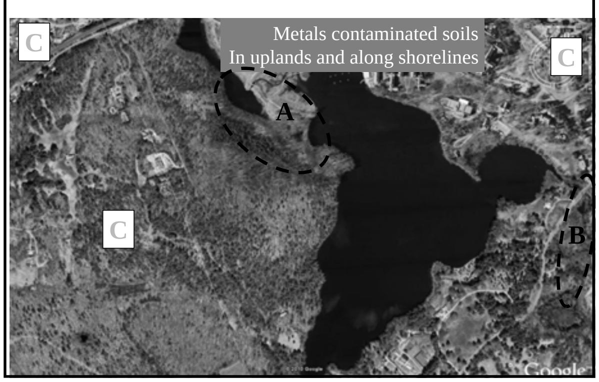
The lake is used for fishing – mainly yellow perch and large mouth bass.

Many wildlife species including waterfowl use the lake and wetlands as habitat.

Our study site



Our study site



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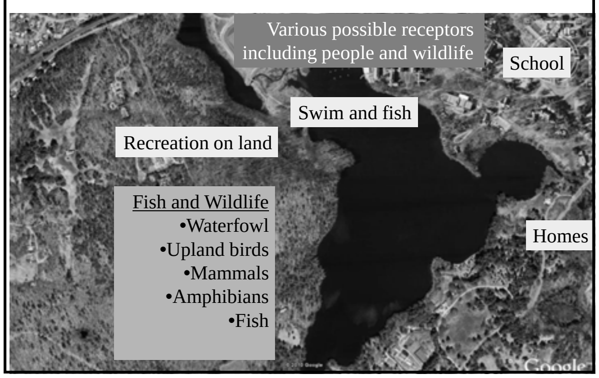

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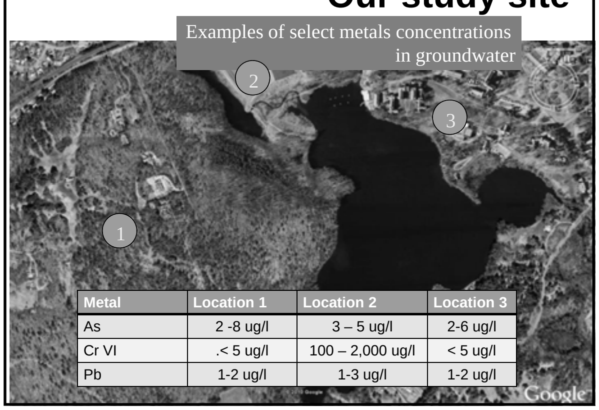

Metal	Location 1	Location 2	Location 3
As	2 -8 ug/l	3 – 5 ug/l	2-6 ug/l
Cr VI	.< 5 ug/l	100 – 2,000 ug/l	< 5 ug/l
Pb	1-2 ug/l	1-3 ug/l	1-2 ug/l

Soil data for A

Compounds	# Analyzed	# Detected	Min	Max	Average
Total Metals (mg/kg dry wt.)					
Arsenic, Total	183	174	2.2	16	8
Cadmium, Total	145	88	0.045	5	1.27
Chromium, Total	394	394	2.15	110000	2883
Copper, Total	117	117	2.7	282	27
Lead, Total	378	373	2.1	214000	5433
Mercury, Total	16	9	0.1	28	2.01
Nickel, Total	142	141	3.2	4900	124
Silver, Total	132	40	0.023	2	1
Chromium III	394	394	2.15	61600	1753
Chromium VI	310	310	0	48400	1436

Sediment data for E

Compounds	# Analyzed	# Detected	Min	Max	Average
Total Metals (mg/kg dry wt.)					
Arsenic, Total	30	30	2.2	8	6
Cadmium, Total	30	30	0.045	3	4
Chromium, Total	30	30	800	10500	2883
Copper, Total	30	30	50	200	70
Lead, Total	30	30	600	15000	6000
Mercury, Total	30	30	0.1	1	0.8
Nickel, Total	30	30	50	3000	1500
Silver, Total	30	30	0.023	2	1
Chromium III	30	30	800	10500	2883
Chromium VI	30	30	ND	ND	

Reference data for soil and sediment

Metal	Local background for soil (mg/kg)	Local reference for sediment (mg/kg)
Arsenic	2 - 16	3 - 8
Cadmium	1 - 5	1 - 4
Chromium total	20 - 40	15 - 30
Copper	10 - 25	15 - 40
Lead	20 -45	30 - 50
Mercury	0.1 - 1	0.1 - 1
Nickel	10 - 35	5 - 45
Silver	0.02 - 3	0.01 - 3

Exercise:
define the problem(s),

develop conceptual model(s)

write down 2 assessment endpoints