Use of Biological Tests in Risk-Based Remediation of Contaminated Sites - A Canadian Perspective

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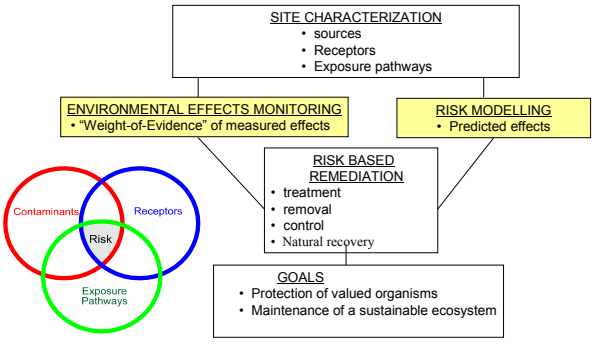
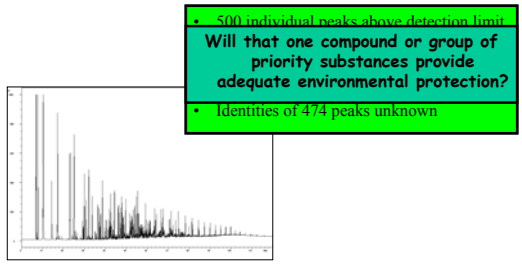
Outline

- Evolution of Risk-based Remediation in Canada
- Chemical Concentrations versus Eco-toxicological Effects
- Ecological Risk Assessment Approach
- Case study:
  - Chemical Warfare Agents (CWA) in soil: Defence Research Facility, Suffield, Alberta.
  - Mercury in soil, groundwater, sediment and biota: Chlor-alkali plant, Squamish, BC.
  - Petroleum Hydrocarbons in sediment: Sawmill, Great Central Lake, Vancouver Island, BC.

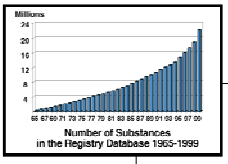
ECOLOGICAL RISK ASSESSMENT

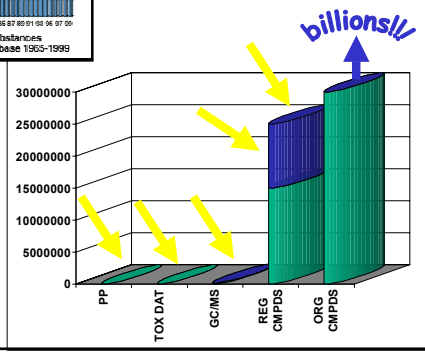


Soil Extract – GC Trace



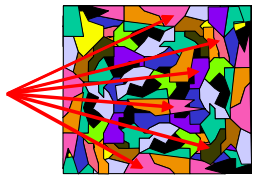
Chemicals



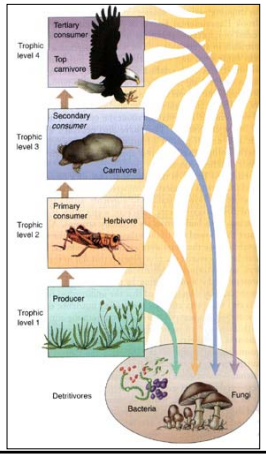


Concentrations vs Effects

Chemical testing is parameter specific



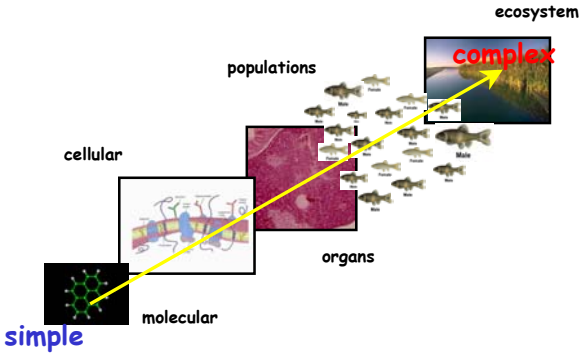
Toxicity testing provides integrated response



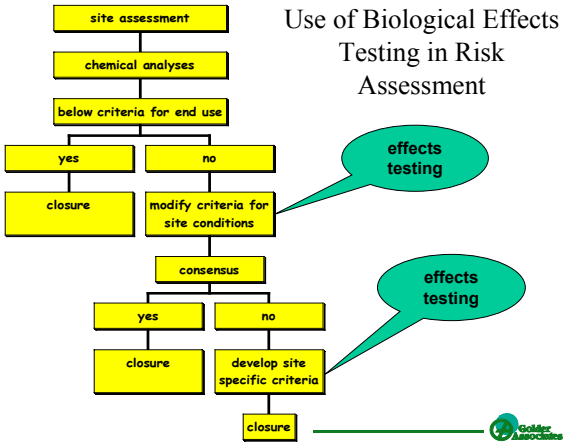
Ecosystem Approach:

Protection of organisms at all trophic levels

Establishing the Appropriate Level of Protection

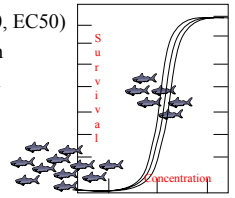


Use of Biological Effects Testing in Risk Assessment



Risk Modelling for Predicting Effects

- Toxicity Based:
  - sensitive species or life-stage
  - acute or chronic
  - endpoint selection (NOEC, LC50, EC50)
    - lab to real world extrapolation
    - between species extrapolation
- Eco-epidemiology:
  - apparent effects thresholds
  - retrospective, field based



"Weight of Evidence" of Ecosystem Effects

1. Ecosystem Community Structure (e.g. diversity and abundance of invertebrates)
2. Soil/Sediment Chemical Characteristics (concentration, mobility and bioavailability)
3. Soil/Sediment Toxicity (Survival, Growth, Reproduction)
4. Bioaccumulation (tissue concentrations)
5. Soil/Sediment Physical Characteristics (grain size, organic matter)

Case Studies – Use of biological tests

1. **Chemical Warfare Agents in soil: Defence Research Facility, Suffield, Alberta, Canada:**
   - Toxicity index for soil dependent receptors: Northern wheatgrass, Earthworm, and Bacteria.
   - Bioaccumulation considered for higher trophic levels: Burrowing owl, Pronghorn antelope, Badger; and Ord's kangaroo rat.
   - Vulnerable, threatened or endangered species considered

The Site

- Canadian Forces Base (CFB) Suffield is located on 2600 km^2 of prairie landscape in south-eastern Alberta.
- The Research Facility was established in 1941 on 500 km^2
- During World War II protection and decontamination were tested
- Following the war, Canada's production stocks of chemical agents were shipped to the Defence Research Facility for safe storage and eventual disposal.
- Trial and tests to develop protective equipment and defensive procedures continued after the war in response to continued threat of chemical warfare.

Destruction of Chemical Warfare Agents

- 700 tons of mustard agent were chemically destroyed by hydrolysis in 1970s.
- Other disposal methods included chemical neutralisation, explosive detonation and open-pit incineration of hazardous items at sites on the EPG.
- The destruction program was completed from 1989 to 1991.
- Materials stored for disposal from the on-site disposal operations included:
  - metal fragments from explosive destruction operations;
  - sludge composed partly of mustard agent;
  - mustard agent or lewisite;
  - caustic methanol decontaminant solution used to neutralise organophosphorous nerve agents.

Ecological Risk Assessment and Remediation Goal

- An Environmental Baseline Study conducted in 1995 assessed approximately 80 locations used for the storage, testing or disposal of Chemical Warfare Agents.
- A preliminary assessment of the ecological risks concluded that 17 locations had high or medium risk of causing environmental impairment.
- Golder conducted a detailed ecological risk assessment of 7 of these locations in 1997, and the remaining 10 in 2002.
- **The goal of the risk assessments was to determine the appropriate remediation actions.**

Remediation Actions Considered

- No Action: based on acceptable low potential for effects
- Excavation and disposal: where effects level were considered to unacceptable, and the soil was amenable to removal and treatment/disposal.
- Partial excavation and containment: excavation and consolidation of contaminated soil in an on-site containment facility
- Surface capping: considered as an alternative to excavation where dust and direct contact at surface were the main exposure pathways (as compared exposure to burrowing animals)
- In-situ soil treatment: considered where the effects were associated with high soil pH due to the use caustic methanol decontaminant solution to neutralise organophosphorous nerve agents.

Toxicity based Investigation

- Toxicity-based to assess the risks and extent of remedial work.
- Geophysical techniques to screen for subsurface contamination or potential hazards.
- Indicator chemicals to screen for deleterious concentrations of CWA:
  - sulphur for mustard-related compounds;
  - metals including arsenic for lewisite;
  - phosphorous for nerve agent
  - pH to indicate use of caustic methanol decontaminant solution
- Detailed chemical testing (metals, PAH, solvents) for trench or burn areas
- CWA analyses for samples suspected of being contaminated, based on indicator chemical testing, toxicity testing, site history and field observations

Health and Safety

- Access to test pits by Golder personnel was restricted until scanned for presence of chemical and/or biological warfare agents
- Personal protective equipment (PPE) included a full face respirator with organic vapour / acid gas / HEPA cartridges, chemical resistant Saranex TYCHEM®SL coveralls, outer Solknit NBR (Nitrite-Butyl-Rubber) gloves duct-taped to the suit with inner nitrile gloves, and steel-toed boots

Criteria for Selection of Receptors

- Guidance for selection of ecological receptors has been provided by the CCME (1996a). Criteria considered include:
  - importance to humans;
  - have economic or social value,
  - have intrinsic ecological significance, and
  - serve as a baseline from which the impacts can be measured.
- Receptors are also selected on the basis of which species are most likely to be affected by the potential contamination at the site.
- Vulnerable, threatened or endangered species considered

Receptor Considerations

Soil-dependent organisms (e.g. plants, invertebrates and microbes) was selected because:

- They are most likely to be effected as the contamination is in the shallow soil.
- The Site is one of the largest areas of remaining natural short-grass prairie in Canada. Soil-dependent organisms are critical to the health of this short-grass prairie ecosystem.

Soil-Dependent Receptors

- *Plants:* The flora are comprised largely of native grasses and sedges that define a short prairie grassland (arid).
- *Terrestrial Invertebrates:* A healthy soil invertebrate community is important to the functioning of the prairie grass ecosystem, and comprises a significant dietary component for numerous other organisms.
- *Soil Microorganisms:* A healthy soil microorganism community is central to nutrient cycling and plant growth. A standard test species (*Vibrio fischeri)* a marine bacteria was used in the Microtox assay, to indicate the effect of soil contamination on microorganisms.

Sensitive Receptors Selected

Receptors selected based on Toxicity:

- Northern wheatgrass (*Agropyron dasystachyum*);
- Earthworm (*Eisenia foetida*); and
- Bacteria (*Vibrio fischeri*).

Receptors selected for bioaccumulative contaminants:

- Burrowing owl (*Athene cunicularia*);
- Pronghorn antelope (*Antilocarous americana*;
- Badger (*Taxidea taxia*); and
- Ord's kangaroo rat (*Dipodomys ordii terrosus*)

Mammalian Wildlife of Concern in the Suffield Area

Species		Status	Agency
Mammals	Black-footed ferret	Extripated	COSEWIC
	Swift fox	Extripated	COSEWIC
	Ord's kangaroo rat	Concern/threatened	PCAP/AFW
	Prairie vole	Concern/threatened	PCAP/AFW
	Badger	Concern	PCAP
	Mule deer	Concern	PCAP
	Western harvest mouse	Concern	PCAP

COSEWIC – Committee on the Status of Endangered Wildlife in Canada, 1994
Species of concern as listed by the Prairie Conservation Action Plan (PCAP 1988)
AFW – Alberta Fish and Wildlife (1991)
Source: Bel MK, 1995.

BIOASSAYS CONDUCTED AT THE EPG SITES

Receptor	Receptor Group	Test Species	Test Endpoint
Microbes	Bacteria	*Vibrio fischeri*	Luminescence
Plants	Grasses	Northern wheatgrass- *Agropyron dasystachyum*	Seedling emergence
Plants	Grasses	Northern wheatgrass- *Agropyron dasystachyum*	Root elongation and germination
Soil invertebrates	Earthworms	*Eisenia foetida*	Survival

BIOASSAY TEST SCORES USED TO EVALUATE SOIL TOXICITY

Bioassay (% of Control)				Test Score
Bacterial Luminescence	Seedling emergence	Root elongation and germination	Earthworm Survival	
75-100	80-100	80-100	80-100	**1**
60-74	60-79	60-79	60-79	**2**
40-59	40-59	40-59	40-59	**3**
20-39	20-39	20-39	20-39	**4**
0-19	0-19	0-19	0-19	**5**

RELATIVE WEIGHTING OF THE BIOASSAY TESTS

Bioassay	Test Weight
Bacterial Luminescence	20%
Seedling emergence	20%
Root elongation and germination	20%
Earthworm Survival	40%

Scoring and Determination of the Soil Toxicity Index

Bioassay	Bacterial Luminescence		Root Elongation		Seedling Emergence		Earthworm Survival		Toxicity Index
Weight	20%		20%		20%		40%		
Sample ID	% Control	Score	% Control	Score	% Control	Score	% Control	Score	
Sample 1	106	1	78	2	79	2	75	2	1.8
Sample 2	98	1	55	3	42	2	62	2	2.0

Scoring and Determination of the Soil Toxicity Index for the Background Soil Samples

Bioassay	Bacterial Luminescence		Root Elongation		Seedling Emergence		Earthworm Survival		Toxicity Index
Weight	20%		20%		20%		40%		
	% Control	Score	% Control	Score	% Control	Score	% Control	Score	
Sample ID									
Vertical Grid Layout									
32100009-1	106	1	78	2	79	2	104	1	**1.4**
32200015-1	123	1	94	1	98	1	107	1	**1**
32300015-1	112	1	129	1	81	1	77	2	**1.4**
Willis Centre Trench									
60100004-1	120	1	97	1	98	1	96	1	**1**
60100004-2	110	1	107	1	105	1	43	3	**1.8**
Chemical Mix Dump									
58100003-1	100	1	81	1	77	2	111	1	**1.2**

Reference Index = > 1.2 x Maximum Background Toxicity Index

BIOASSAY SCORING FOR THE 490 COMPOUND (DRES SITE 40) TARGET AREA 1

Bioassay	Bacterial Luminescence		Root Elongation		Seedling Emergence		Earthworm Survival		Toxicity Index
Weight	20%		20%		20%		40%		
	% Control	Score	% Control	Score	% Control	Score	% Control	Score	
Sample ID									
40110004-1	39	4	131	1	4	5	0	5	**4**
40110005-1	34	4	166	1	0	5	7	5	**4**
Reference Index									**2.2**

Bioassay Scoring for the Cameron Decontamination Center

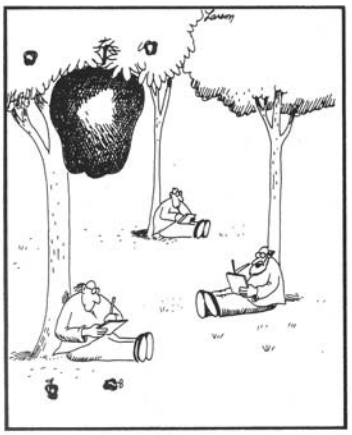
Bioassay	Bacterial Luminescence		Root Elongation		Seedling Emergence		Earthworm Survival		Toxicity Index
Weight	20%		20%		20%		40%		
	% Control	Score	% Control	Score	% Control	Score	% Control	Score	
Sample ID									
38200005-1	98	1	175	1	86	1	104	1	**1**
38210001-1	151	1	216	1	93	1	100	1	**1**
38210001-2	139	1	175	1	93	1	36	4	**2.2**
38210002-1	106	1	161	1	93	1	11	5	**2.6**
38210002-2	148	1	153	1	82	1	107	1	**1**
38210003-1	155	1	137	1	86	1	107	1	**1**
38210003-2	140	1	176	1	95	1	32	4	**2.2**
38210004-1	117	1	148	1	82	1	104	1	**1**
38210004-2	109	1	167	1	89	1	100	1	**1**
38210006-1	84	1	175	1	88	1	21	4	**2.2**
38210006-2	98	1	204	1	96	1	61	2	**1.4**
38210006-3	73	2	181	1	89	1	18	5	**2.8**
Reference Index									**2.2**

*-Background Sample


064

Case Studies – Use of biological tests

1. **Chemical Warfare Agents in soil: Defence Research Facility, Suffield, Alberta, Canada:**
   - Toxicity index for soil dependent receptors: Northern wheatgrass, Earthworm, and Bacteria.
   - Bioaccumulation considered for higher trophic levels: Burrowing owl, Pronghorn antelope, Badger; and Ord's kangaroo rat.
2. Mercury in soil, groundwater, sediment and biota: Chlor-alkali plant, Squamish, BC.:
   - Measurement of tissue concentrations in biota at several trophic levels: plants, earthworms, shrews, moles, mussels, crab, several species of fish, birds.
3. Petroleum Hydrocarbons in sediment: Sawmill, Great Central Lake, Vancouver Island, BC.:
   - Toxicity tests of benthic invertbrates: chironomus and hyalella



"Nothing yet . . . How about you, Newton?"